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METHODS FOR EVALUATING THE PREDICTIVE ACCURACY OF STRUCTURAL DYNAMIC MODELS

Quarterly Report No. 6

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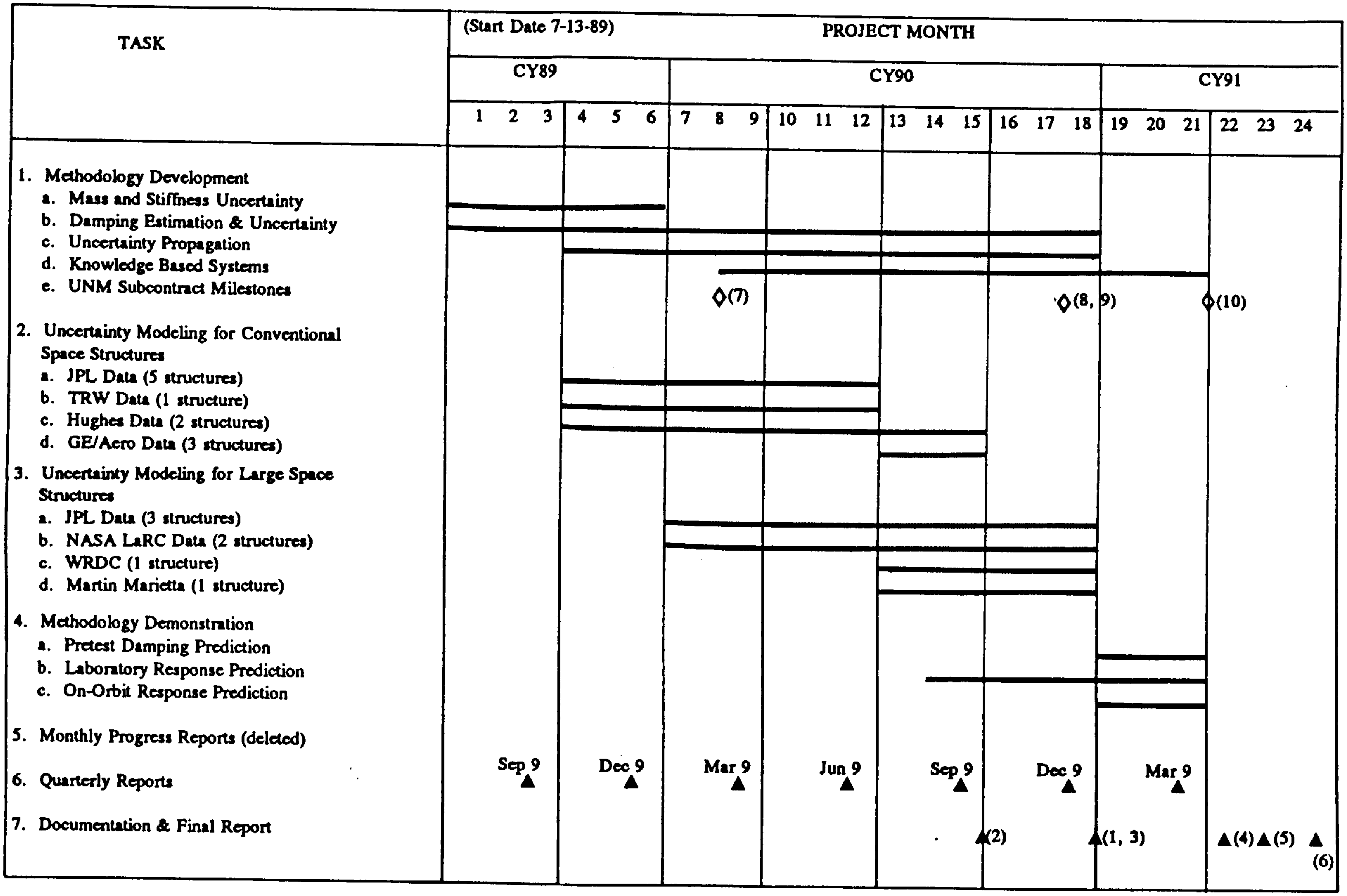
1. PROGRESS SUMMARY

This report covers the period of performance from 1 September, 1990 through 30 November, 1990. Some of the work originally planned for this quarter was not completed due to illness, the unavailability of test data from the NASA Langley Research Center, and other project demands not previously anticipated. The schedule presented in the last quarterly report [1] is shown again in Table 1 for reference. It has not been updated pending the anticipated rescheduling of another EMA project in which EMA is a subcontractor.

The probable impact of these factors on the present schedule is that a no cost extension of the contract will have to be requested. Sufficient information to base this request should be forthcoming within the next month so that the request can be finalized in January. At that time a revised schedule will be proposed. As it presently stands, the Interim Report on Uncertainty Modeling for Conventional Space Structures has not been completed and the Interim Reports on Methodology and Uncertainty Modeling for Large Space Structures will not be finished by the end of December. The delays are due in part to the loss of typing support for two months during October and November because of illness.

Work during this reporting period focused primarily on two task areas; Task 1c, Uncertainty Propagation using the Fuzzy Set Method and Task 4c, On-orbit Response Prediction using laboratory test data to refine an analytical model. Extensive printer graphics have been added to the SSID code to help facilitate model verification. An application of this code to the LaRC Ten Bay Truss previously reported in [1] is included in the appendix of this report to illustrate this graphics capability.

Table 1. Project Schedule



Notes:

(1) Interim report on methodology
(2) Interim report on uncertainty model for conventional space structures
(3) Interim report on uncertainty model for large space structures
(4), (5), (6) Final report: Draft, Review, Final
(7) UNM subcontract start
(8) UNM complete task on uncertainty propagation
(9) UNM complete task on knowledge based systems
(10) UNM final report

2. DATA ACQUISITION

In September, Tim Hasselman and Jon Chrostowski visited the NASA Langley Research Center to observe system identification tests being performed on the CSI Evolutionary Structure. A detailed briefing was presented to approximately 15 LaRC personnel, covering the objectives of the present contract and progress to date. Plans to use analytical data and test data from the CSI Evolutionary Structure were also presented and procedures for acquiring the data were discussed with Keith Belvin, the LaRC Project Manager. NASTRAN bulk data input for the finite element model of the structure was obtained along with computer plots of nodal geometry showing the locations of actuators and sensors. See Figure 1. Photographs of the test setup were obtained and additional photographs were taken.

LaRC is currently processing these data and tuning their finite element model. Test data including frequency response functions and experimentally derived eigenvalues and eigenvectors are now available. John Garba, the Contract Technical Monitor at JPL has been consulted about transmitting the data from LaRC to JPL. He and Keith Belvin have been in communication with each other regarding this matter and are in agreement that the data can be transmitted via LaRC's TCP/IP computer data link. EMA will prepare a detailed list of the data requested and submit it in writing to LaRC. Following transmittal of the data, EMA will edit it and either download it to EMA computers via telephone link or write it on tape or disk at JPL.

In addition to the CSI Evolutionary Structure data, more ERA data for the Ten Bay Truss were obtained while visiting LaRC. These data constitute multiple realization of complex eigenvalues and eigenvectors to be used in damping estimation.

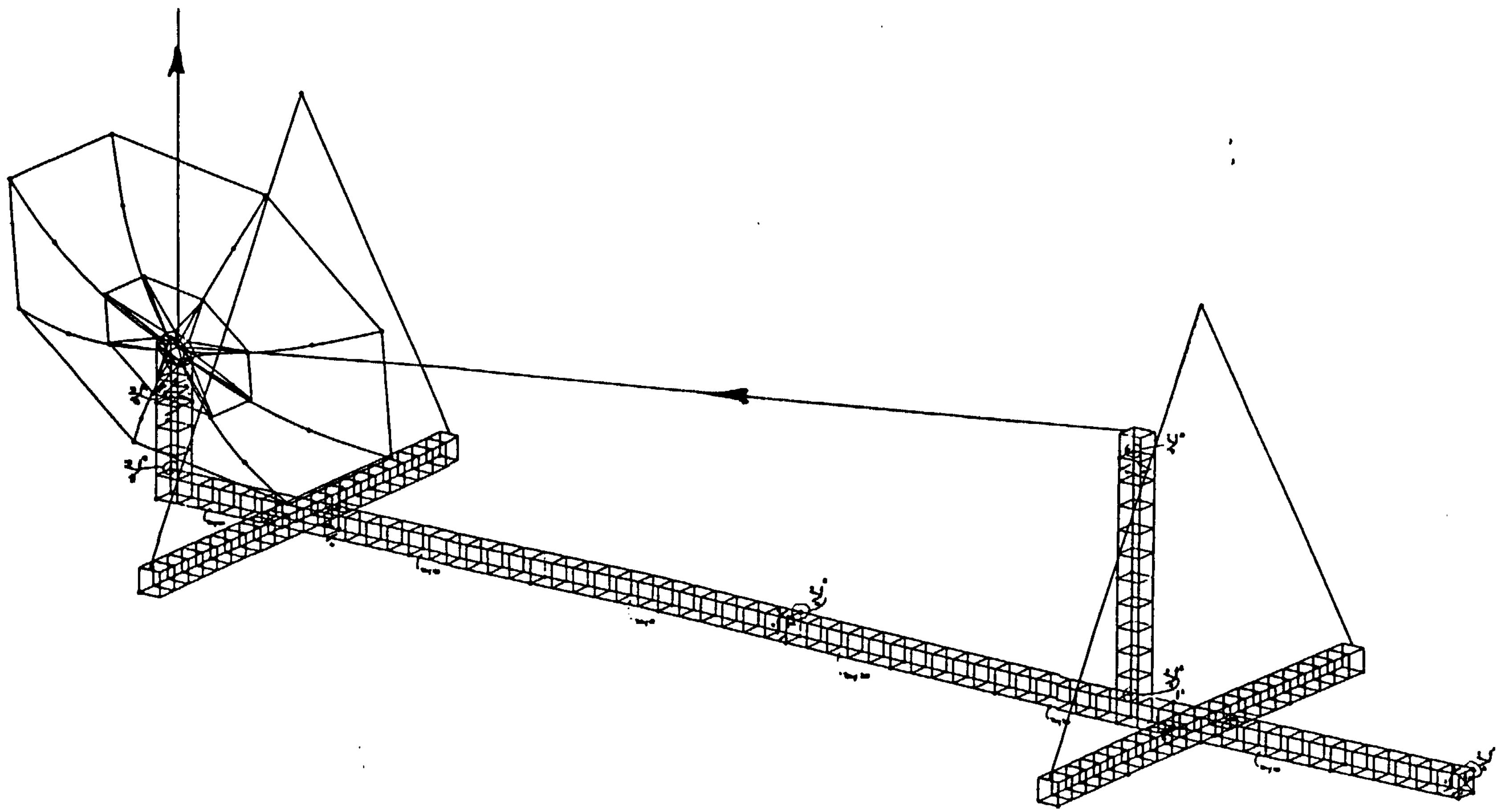


Figure 1. Nodal Geometry of LaRC's CSI Evolutionary Structure

3. PRELIMINARY RESULTS

3.1 Frequency Response of the Ten Bay Truss

The problem of evaluating the uncertainty of frequency response characteristics based on uncertainties associated with the modal parameters of a structural model was introduced in [2]. There it was shown that the first order statistical method provided an excellent approximation (compared to Monte Carlo simulation) at off-resonant frequencies, but as expected, diverged near resonance. Fuzzy set methods, on the other hand, were shown to be useful at or near resonance for purposes of bounding uncertainties. Numerical demonstrations based on simple models were used to illustrate the principle of evaluating possibility intervals in the case of fuzzy sets, as opposed to probability distributions derived from conventional methods of probability and statistics. Two aspects of the fuzzy set approach were to be investigated relative to its application to large structural dynamics problems:

1. Minimizing the number of parameters involved in computing possibility intervals, and

2. The treatment of extrema which may occur in the parameter space enclosed by all possible combination of the important parameters of the model.

These topics have been explored using the LaRC Ten Bay Truss as a working example.

Several frequency response functions (FRF) were first computed for the Ten Bay Truss using SSID. These FRF represent displacement response at the free end of the cantilever truss structure, due to force also applied at the free end. Figure 2 illustrates the nodal geometry of the finite element model. Figure 3 shows the first nine analytical modes derived from the NASTRAN model.

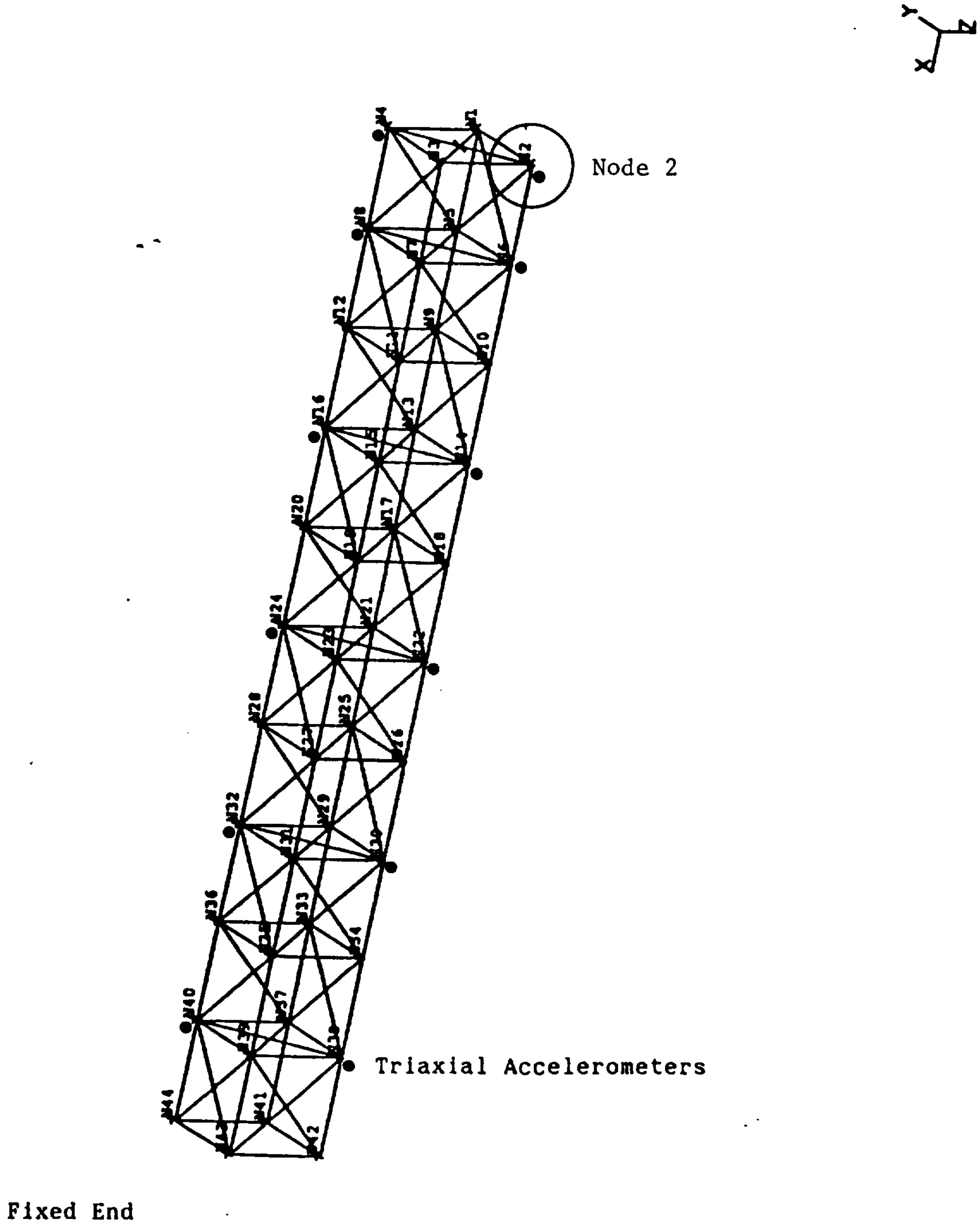


Figure 2. Nodal Geometry of LaRC Ten Bay Truss Structure.

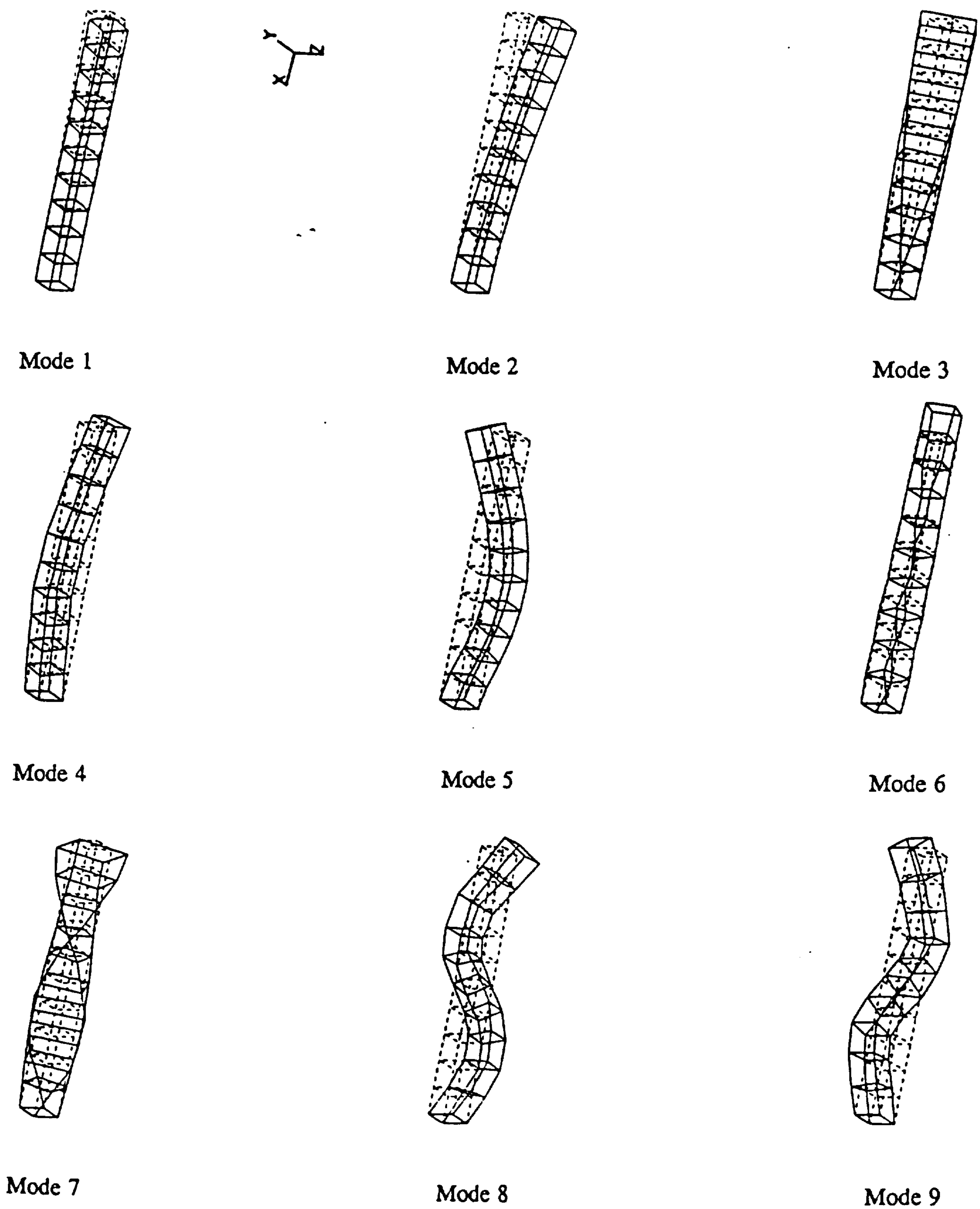


Figure 3. Analytical modes of the NASA LaRC Ten Bay Truss.

Modal frequencies are listed in Table 2. Figures 4 through 7 show the amplitude and phase of several complex FRF over the range of 10 to 100 Hz which includes the first five modes.

Table 2. Analytical Frequencies of the Ten Bay Truss, LaRC NASTRAN Model

Mode No.	Frequency Hz	Mode Description
1	17.889	1st Y-Bending
2	17.892	1st Z-Bending
3	63.047	1st Torsion
4	93.569	2nd ZY-Bending
5	94.011	2nd YZ-Bending
6	170.668	1st Axial
7	192.093	2nd Torsion
8	219.786	3rd Z-Bending
9	225.218	3rd Y-Bending

FREQ-HZ	DISPL/FORCE
1.00000E+01	3.88433E-03
1.04713E+01	4.05532E-03
1.09648E+01	4.26167E-03
1.14815E+01	4.51440E-03
1.20226E+01	4.82960E-03
1.25893E+01	5.23172E-03
1.31826E+01	5.75978E-03
1.38038E+01	6.48014E-03
1.44544E+01	7.51523E-03
1.51356E+01	9.11814E-03
1.58489E+01	1.19062E-02
1.65959E+01	1.78388E-02
1.73780E+01	3.65829E-02
1.81970E+01	4.58815E-02
1.90546E+01	1.77907E-02
1.99526E+01	1.01356E-02
2.08930E+01	6.81523E-03
2.18776E+01	4.98472E-03
2.29087E+01	3.83207E-03
2.39883E+01	3.04297E-03
2.51189E+01	2.47096E-03
2.63027E+01	2.03872E-03
2.75423E+01	1.70164E-03
2.88403E+01	1.43216E-03
3.01995E+01	1.21235E-03
3.16228E+01	1.03001E-03
3.31131E+01	8.76515E-04
3.46737E+01	7.45618E-04
3.63078E+01	6.32613E-04
3.80189E+01	5.33862E-04
3.98107E+01	4.46450E-04
4.16869E+01	3.67934E-04
4.36516E+01	2.96131E-04
4.57088E+01	2.28896E-04
4.78630E+01	1.63829E-04
5.01187E+01	9.78401E-05
5.24807E+01	2.86764E-05
5.49541E+01	7.20700E-05
5.75440E+01	2.17497E-04
6.02560E+01	5.97013E-04
6.30957E+01	2.94114E-03
6.60693E+01	5.87631E-04
6.91831E+01	2.83396E-04
7.24436E+01	1.49495E-04
7.58578E+01	5.63377E-05
7.94328E+01	3.85290E-05
8.31764E+01	1.53429E-04
8.70964E+01	3.78669E-04
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9.54993E+01	1.32523E-03
1.00000E+02	5.17675E-04

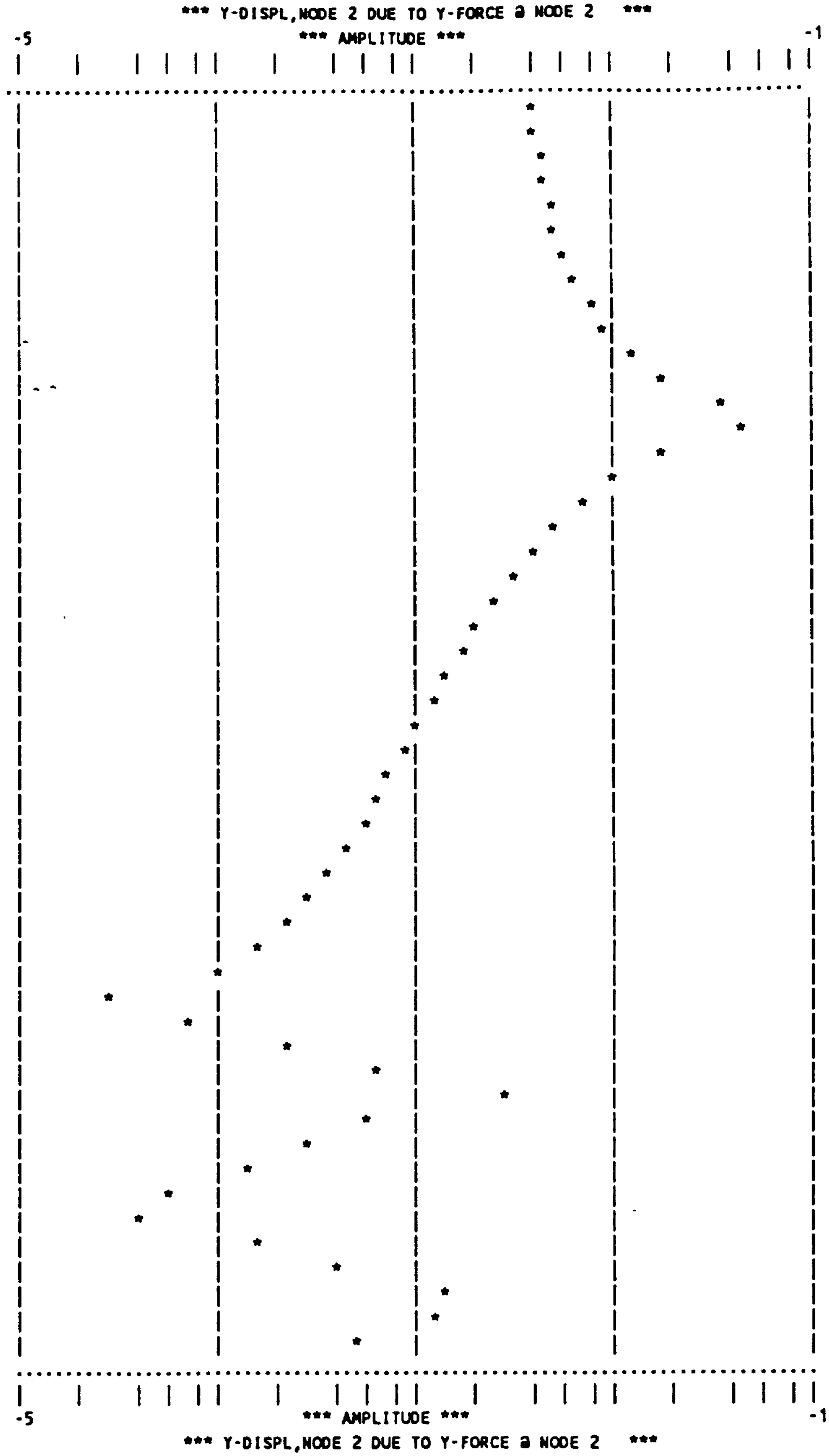
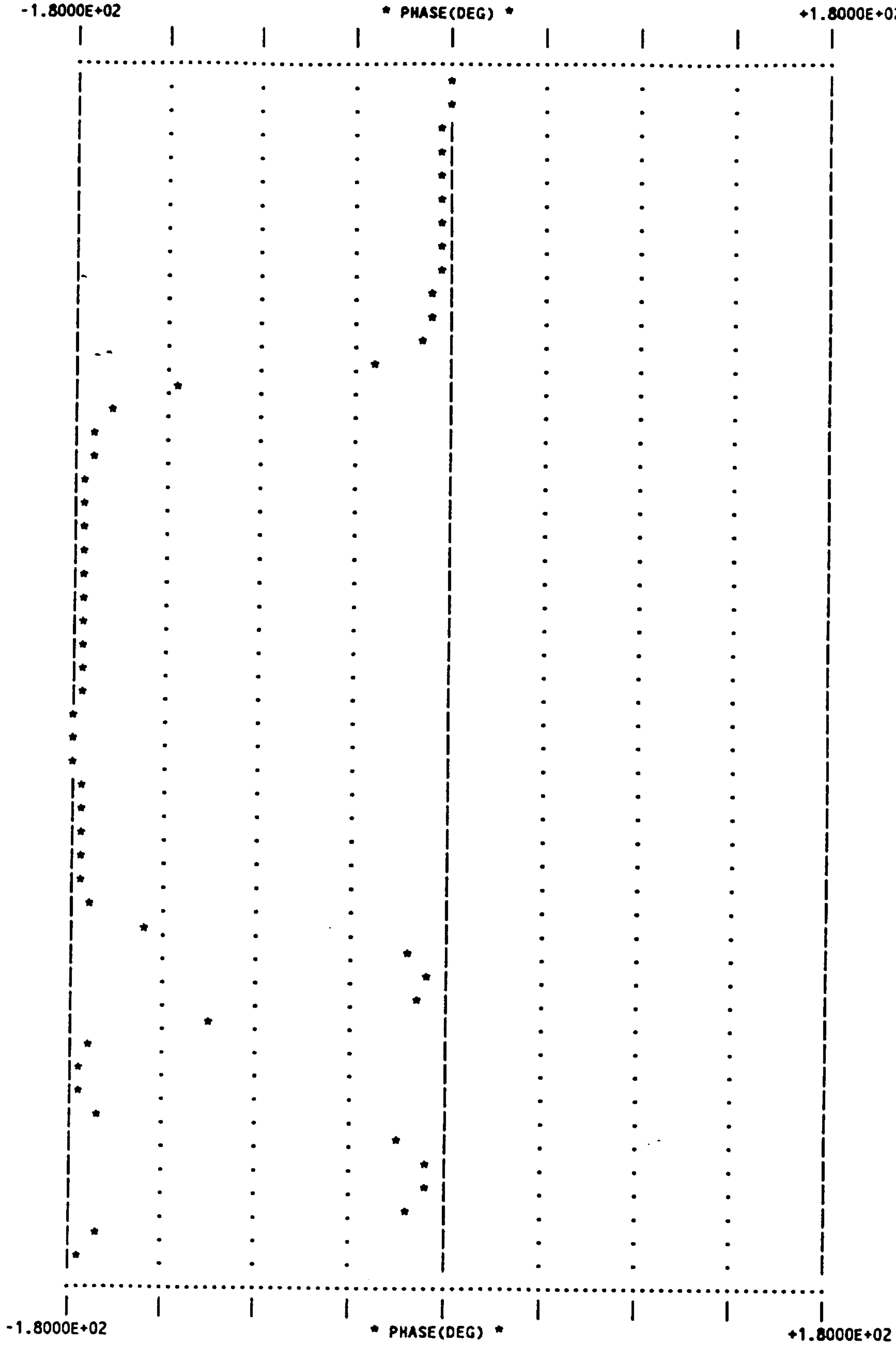


Figure 4a. FRF Amplitude, LaRC Ten Bay Truss, Y-Displacement/Y-Force at Node 2.

*** Y-DISPL,NODE 2 DUE TO Y-FORCE @ NODE 2 ***

FREQ-HZ	PHSE-DEG
1.00000E+01	-1.92227E+00
1.04713E+01	-2.10810E+00
1.09648E+01	-2.32787E+00
1.14815E+01	-2.59212E+00
1.20226E+01	-2.91627E+00
1.25893E+01	-3.32378E+00
1.31826E+01	-3.85217E+00
1.38038E+01	-4.56540E+00
1.44544E+01	-5.58189E+00
1.51356E+01	-7.14765E+00
1.58489E+01	-9.86824E+00
1.65959E+01	-1.57092E+01
1.73780E+01	-3.53769E+01
1.81970E+01	-1.30974E+02
1.90546E+01	-1.61331E+02
1.99526E+01	-1.68801E+02
2.08930E+01	-1.72008E+02
2.18776E+01	-1.73775E+02
2.29087E+01	-1.74888E+02
2.39883E+01	-1.75651E+02
2.51189E+01	-1.76203E+02
2.63027E+01	-1.76618E+02
2.75423E+01	-1.76937E+02
2.88403E+01	-1.77187E+02
3.01995E+01	-1.77382E+02
3.16228E+01	-1.77533E+02
3.31131E+01	-1.77644E+02
3.46737E+01	-1.77718E+02
3.63078E+01	-1.77753E+02
3.80189E+01	-1.77743E+02
3.98107E+01	-1.77674E+02
4.16869E+01	-1.77517E+02
4.36516E+01	-1.77215E+02
4.57088E+01	-1.76632E+02
4.78630E+01	-1.75377E+02
5.01187E+01	-1.71820E+02
5.24807E+01	-1.45273E+02
5.49541E+01	-1.83541E+01
5.75440E+01	-1.12246E+01
6.02560E+01	-1.49495E+01
6.30957E+01	-1.14148E+02
6.60693E+01	-1.69872E+02
6.91831E+01	-1.73641E+02
7.24436E+01	-1.73245E+02
7.58578E+01	-1.65556E+02
7.94328E+01	-2.31737E+01
8.31764E+01	-8.47775E+00
8.70964E+01	-8.21203E+00
9.12011E+01	-1.91942E+01
9.54993E+01	-1.66614E+02
1.00000E+02	-1.75521E+02



*** Y-DISPL,NODE 2 DUE TO Y-FORCE @ NODE 2 ***

Figure 4b. FRF Phase, LaRC Ten Bay Truss, Y-Displacement/Y-Force at Node 2.

FREQ-HZ	DISPL/FORCE
1.00000E+01	7.39314E-05
1.04713E+01	7.56281E-05
1.09648E+01	7.80223E-05
1.14815E+01	8.15142E-05
1.20226E+01	8.67959E-05
1.25893E+01	9.51084E-05
1.31826E+01	1.08773E-04
1.38038E+01	1.32379E-04
1.44544E+01	1.75786E-04
1.51356E+01	2.63334E-04
1.58489E+01	4.70241E-04
1.65959E+01	1.13665E-03
1.73780E+01	5.55905E-03
1.81970E+01	1.01020E-02
1.90546E+01	1.43184E-03
1.99526E+01	4.99848E-04
2.08930E+01	2.53568E-04
2.18776E+01	1.60453E-04
2.29087E+01	1.19517E-04
2.39883E+01	1.00452E-04
2.51189E+01	9.14910E-05
2.63027E+01	8.74715E-05
2.75423E+01	8.60218E-05
2.88403E+01	8.60290E-05
3.01995E+01	8.69670E-05
3.16228E+01	8.85960E-05
3.31131E+01	9.08263E-05
3.46737E+01	9.36590E-05
3.63078E+01	9.71614E-05
3.80189E+01	1.01464E-04
3.98107E+01	1.06775E-04
4.16869E+01	1.13409E-04
4.36516E+01	1.21851E-04
4.57088E+01	1.32872E-04
4.78630E+01	1.47766E-04
5.01187E+01	1.68883E-04
5.24807E+01	2.00960E-04
5.49541E+01	2.55184E-04
5.75440E+01	3.65723E-04
6.02560E+01	7.08192E-04
6.30957E+01	2.88894E-03
6.60693E+01	5.30821E-04
6.91831E+01	2.60993E-04
7.24436E+01	1.64465E-04
7.58578E+01	1.15061E-04
7.94328E+01	8.50167E-05
8.31764E+01	6.45854E-05
8.70964E+01	4.85836E-05
9.12011E+01	1.64474E-05
9.54993E+01	3.86396E-05
1.00000E+02	2.40397E-05

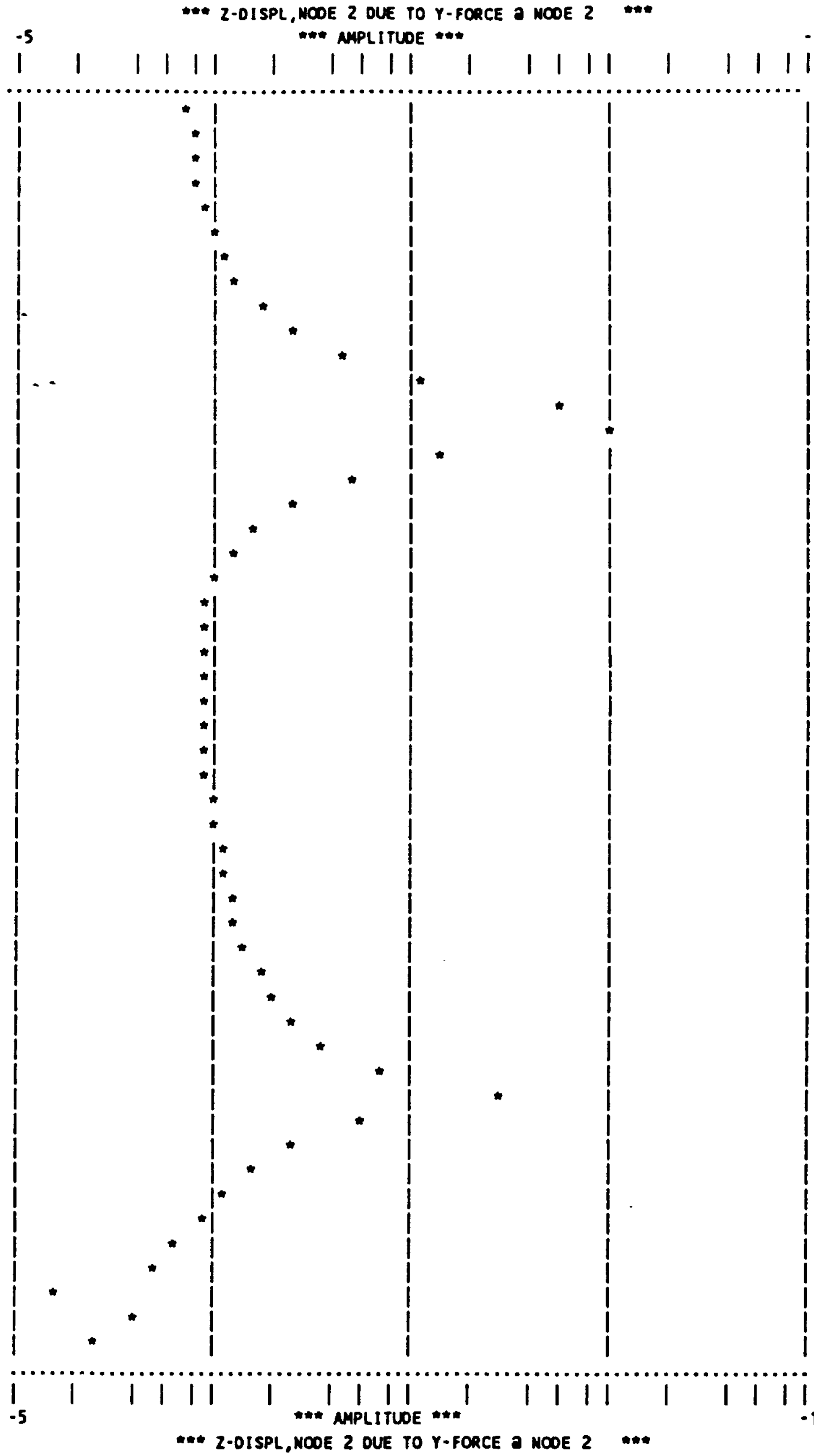


Figure 5a. FRF Amplitude, LaRC Ten Bay Truss, Z-Displacement/Y-Force at Node 2.

FREQ-HZ	PHSE-DEG
1.00000E+01	-2.46195E+01
1.04713E+01	-2.77753E+01
1.09648E+01	-3.15886E+01
1.14815E+01	-3.62215E+01
1.20226E+01	-4.18550E+01
1.25893E+01	-4.86586E+01
1.31826E+01	-5.67271E+01
1.38038E+01	-6.59914E+01
1.44544E+01	-7.61783E+01
1.51356E+01	-8.69752E+01
1.58489E+01	-9.86372E+01
1.65959E+01	-1.14008E+02
1.73780E+01	-1.53137E+02
1.81970E+01	1.20461E+00
1.90546E+01	-5.49421E+01
1.99526E+01	-6.25796E+01
2.08930E+01	-5.95856E+01
2.18776E+01	-5.17640E+01
2.29087E+01	-4.20865E+01
2.39883E+01	-3.27980E+01
2.51189E+01	-2.50791E+01
2.63027E+01	-1.91348E+01
2.75423E+01	-1.47022E+01
2.88403E+01	-1.14237E+01
3.01995E+01	-8.99139E+00
3.16228E+01	-7.17404E+00
3.31131E+01	-5.80656E+00
3.46737E+01	-4.77281E+00
3.63078E+01	-3.99142E+00
3.80189E+01	-3.40546E+00
3.98107E+01	-2.97567E+00
4.16869E+01	-2.67612E+00
4.36516E+01	-2.49206E+00
4.57088E+01	-2.41971E+00
4.78630E+01	-2.46912E+00
5.01187E+01	-2.67265E+00
5.24807E+01	-3.10865E+00
5.49541E+01	-3.97532E+00
5.75440E+01	-5.89477E+00
6.02560E+01	-1.21352E+01
6.30957E+01	-1.12624E+02
6.60693E+01	-1.69333E+02
6.91831E+01	-1.74246E+02
7.24436E+01	-1.75999E+02
7.58578E+01	-1.76941E+02
7.94328E+01	-1.77651E+02
8.31764E+01	-1.78562E+02
8.70964E+01	1.78776E+02
9.12011E+01	1.16723E+02
9.54993E+01	1.43889E+02
1.00000E+02	1.75388E+02

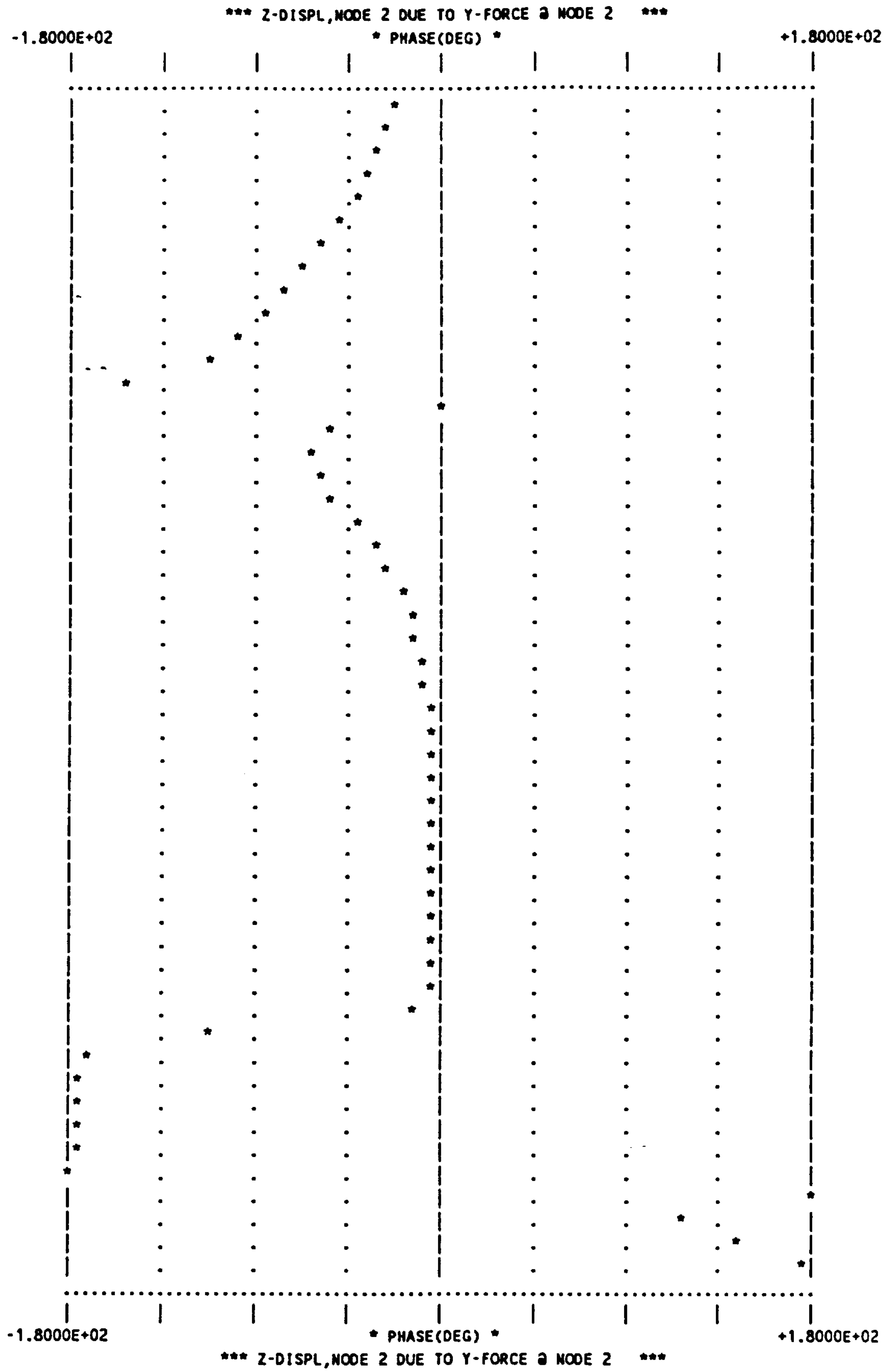
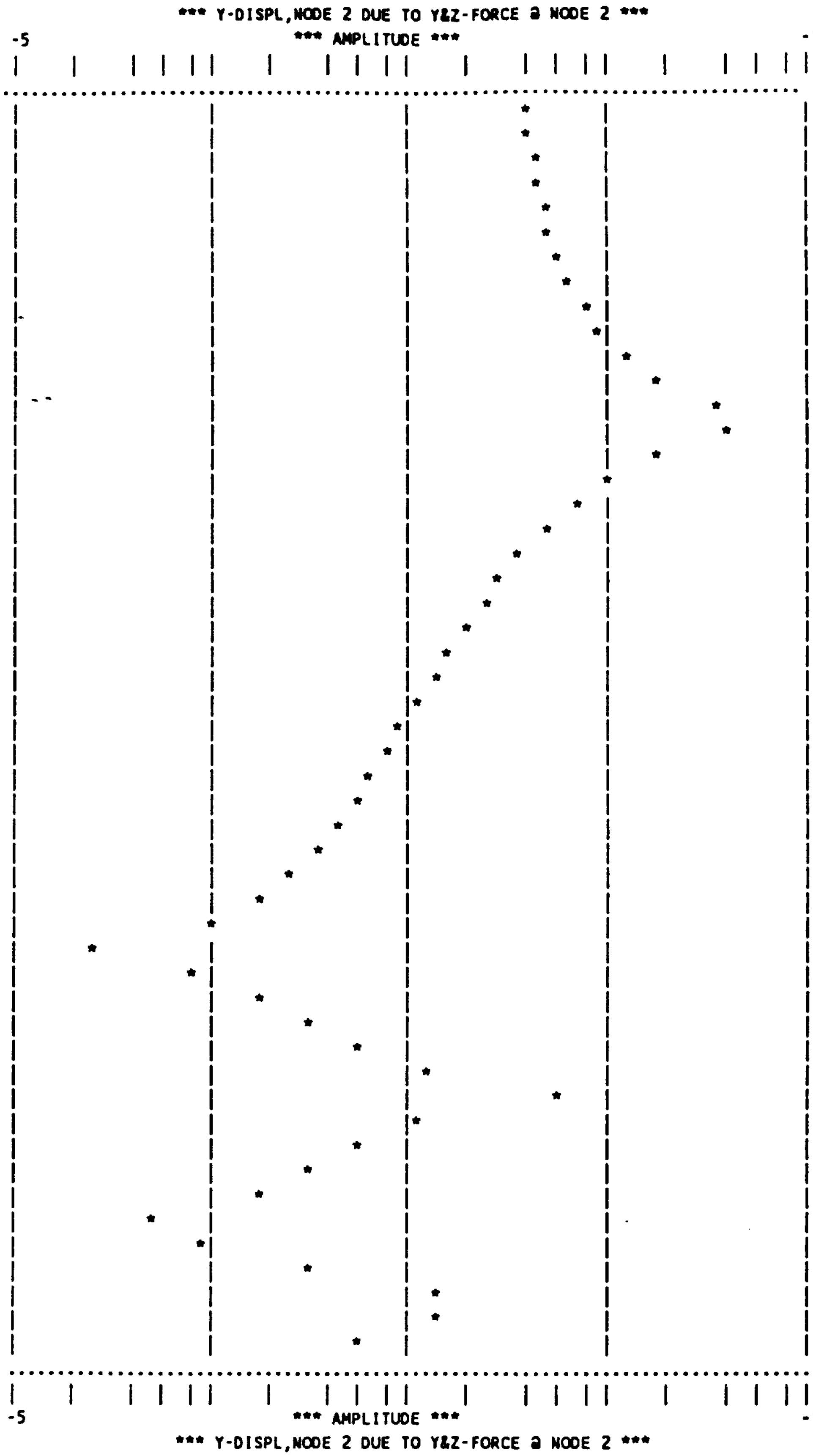


Figure 5b. FRF Phase, LaRC Ten Bay Truss, Z-Displacement/Y-Force at Node 2.



FREQ-HZ	DISPL/FORCE
1.00000E+01	3.95263E-03
1.04713E+01	4.12362E-03
1.09648E+01	4.32991E-03
1.14815E+01	4.58249E-03
1.20226E+01	4.89741E-03
1.25893E+01	5.29901E-03
1.31826E+01	5.82608E-03
1.38038E+01	6.54449E-03
1.44544E+01	7.57544E-03
1.51356E+01	9.16831E-03
1.58489E+01	1.19255E-02
1.65959E+01	1.77105E-02
1.73780E+01	3.43477E-02
1.81970E+01	3.98089E-02
1.90546E+01	1.74409E-02
1.99526E+01	1.00074E-02
2.08930E+01	6.72259E-03
2.18776E+01	4.90156E-03
2.29087E+01	3.75189E-03
2.39883E+01	2.96353E-03
2.51189E+01	2.39125E-03
2.63027E+01	1.95820E-03
2.75423E+01	1.61993E-03
2.88403E+01	1.34894E-03
3.01995E+01	1.12730E-03
3.16228E+01	9.42777E-04
3.31131E+01	7.86715E-04
3.46737E+01	6.52770E-04
3.63078E+01	5.36131E-04
3.80189E+01	4.33008E-04
3.98107E+01	3.40275E-04
4.16869E+01	2.55188E-04
4.36516E+01	1.75155E-04
4.57088E+01	9.76250E-05
4.78630E+01	2.50687E-05
5.01187E+01	7.50876E-05
5.24807E+01	1.79177E-04
5.49541E+01	3.25489E-04
5.75440E+01	5.82630E-04
6.02560E+01	1.30481E-03
6.30957E+01	5.82956E-03
6.60693E+01	1.11844E-03
6.91831E+01	5.44381E-04
7.24436E+01	3.13870E-04
7.58578E+01	1.70653E-04
7.94328E+01	5.29190E-05
8.31764E+01	9.04950E-05
8.70964E+01	3.30499E-04
9.12011E+01	1.42043E-03
9.54993E+01	1.35064E-03
1.00000E+02	5.41427E-04

Figure 6a. FRF Amplitude, LaRC Ten Bay Truss, Y-Displacement/Y and Z-Force at Node 2.

FREQ-HZ	PHSE-DEG
1.00000E+01	-2.33579E+00
1.04713E+01	-2.56326E+00
1.09648E+01	-2.83252E+00
1.14815E+01	-3.15658E+00
1.20226E+01	-3.55448E+00
1.25893E+01	-4.05520E+00
1.31826E+01	-4.70511E+00
1.38038E+01	-5.58325E+00
1.44544E+01	-6.83601E+00
1.51356E+01	-8.76766E+00
1.58489E+01	-1.21276E+01
1.65959E+01	-1.93503E+01
1.73780E+01	-4.36111E+01
1.81970E+01	-1.20134E+02
1.90546E+01	-1.56813E+02
1.99526E+01	-1.66052E+02
2.08930E+01	-1.70010E+02
2.18776E+01	-1.72184E+02
2.29087E+01	-1.73549E+02
2.39883E+01	-1.74478E+02
2.51189E+01	-1.75144E+02
2.63027E+01	-1.75638E+02
2.75423E+01	-1.76009E+02
2.88403E+01	-1.76288E+02
3.01995E+01	-1.76492E+02
3.16228E+01	-1.76631E+02
3.31131E+01	-1.76705E+02
3.46737E+01	-1.76709E+02
3.63078E+01	-1.76625E+02
3.80189E+01	-1.76419E+02
3.98107E+01	-1.76013E+02
4.16869E+01	-1.75227E+02
4.36516E+01	-1.73547E+02
4.57088E+01	-1.68743E+02
4.78630E+01	-1.28680E+02
5.01187E+01	-1.68748E+01
5.24807E+01	-8.74247E+00
5.49541E+01	-7.12736E+00
5.75440E+01	-7.88194E+00
6.02560E+01	-1.34225E+01
6.30957E+01	-1.13392E+02
6.60693E+01	-1.69616E+02
6.91831E+01	-1.73931E+02
7.24436E+01	-1.74688E+02
7.58578E+01	-1.73204E+02
7.94328E+01	-1.59368E+02
8.31764E+01	-1.55374E+01
8.70964E+01	-9.23674E+00
9.12011E+01	-1.87327E+01
9.54993E+01	-1.67861E+02
1.00000E+02	-1.75923E+02

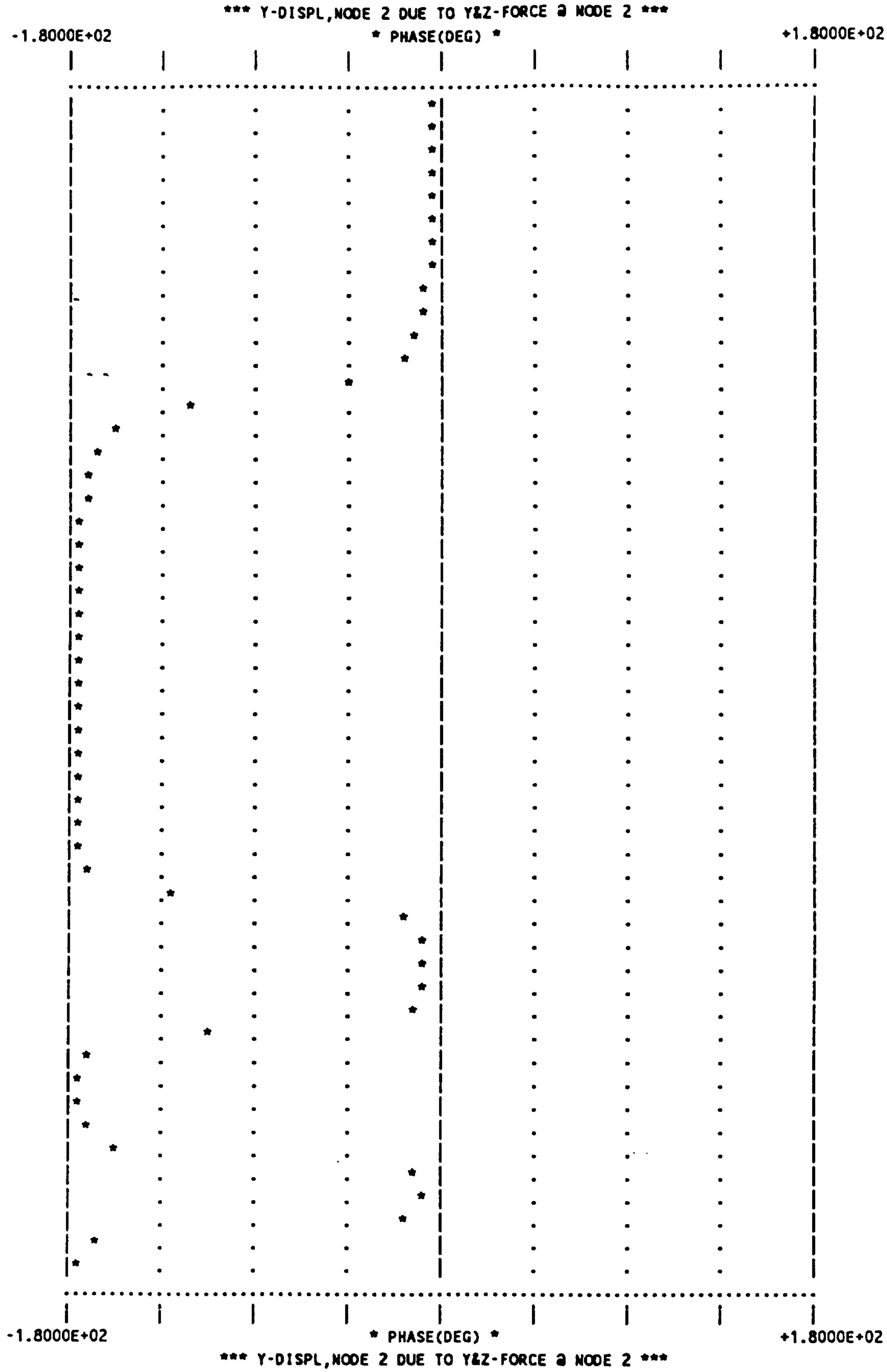


Figure 6b. FRF Phase, LaRC Ten Bay Truss, Y-Displacement/Y and Z-Force at Node 2.

FREQ-HZ	DISPL/FORCE
.00000E+01	3.94483E-03
1.04713E+01	4.11593E-03
1.09648E+01	4.32239E-03
.14815E+01	4.57525E-03
.20226E+01	4.89060E-03
1.25893E+01	5.29290E-03
.31826E+01	5.82121E-03
.38038E+01	6.54193E-03
.44544E+01	7.57769E-03
1.51356E+01	9.18220E-03
.58489E+01	1.19754E-02
.65959E+01	1.79349E-02
1.73780E+01	3.70835E-02
1.81970E+01	4.69846E-02
.90546E+01	1.77789E-02
.99526E+01	1.00774E-02
2.08930E+01	6.74940E-03
2.18776E+01	4.91640E-03
.29087E+01	3.76236E-03
.39883E+01	2.97214E-03
2.51189E+01	2.39899E-03
.63027E+01	1.96551E-03
.75423E+01	1.62703E-03
2.88403E+01	1.35594E-03
3.01995E+01	1.13427E-03
.16228E+01	9.49749E-04
.31131E+01	7.93714E-04
3.46737E+01	6.59813E-04
3.63078E+01	5.43230E-04
.80189E+01	4.40171E-04
.98107E+01	3.47506E-04
4.16869E+01	2.62488E-04
4.36516E+01	1.82503E-04
.57088E+01	1.04886E-04
.78630E+01	2.93779E-05
5.01187E+01	6.66319E-05
.24807E+01	1.70397E-04
.49541E+01	3.16163E-04
5.75440E+01	5.72189E-04
6.02560E+01	1.29107E-03
.30957E+01	5.80411E-03
.60693E+01	1.12037E-03
6.91831E+01	5.49202E-04
7.24436E+01	3.19873E-04
.58578E+01	1.77428E-04
.94328E+01	5.99646E-05
8.31764E+01	8.18937E-05
.70964E+01	3.19792E-04
.12011E+01	1.40500E-03
9.54993E+01	1.34183E-03
1.00000E+02	5.42553E-04

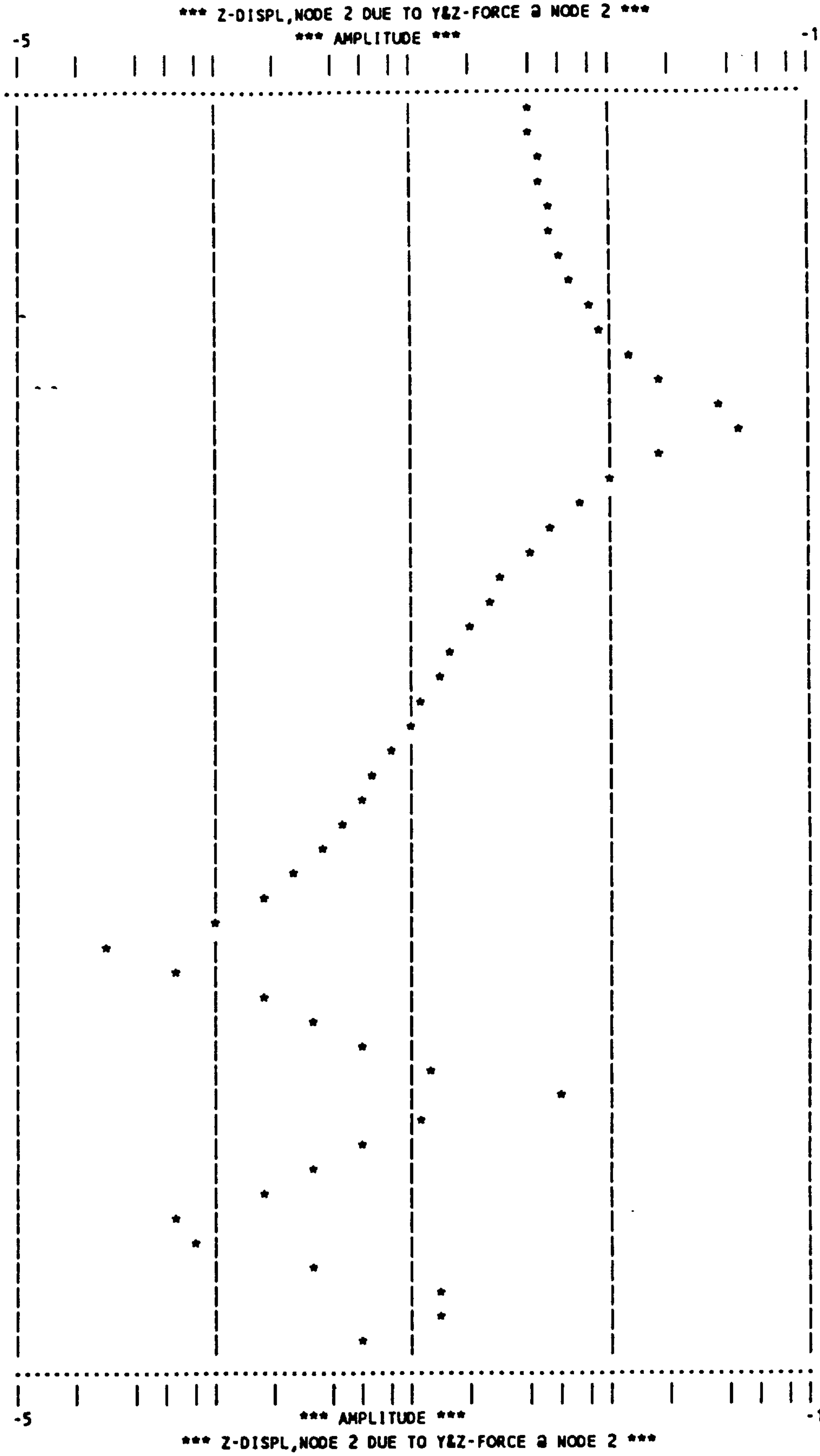


Figure 7a. FRF Amplitude, LaRC Ten Bay Truss, Z-Displacement/Y and Z-Force at Node 2.

FREQ-HZ	PHSE-DEG
1.00000E+01	-1.81861E+00
1.04713E+01	-1.99543E+00
1.09648E+01	-2.20472E+00
1.14815E+01	-2.45655E+00
1.20226E+01	-2.76573E+00
1.25893E+01	-3.15475E+00
1.31826E+01	-3.65961E+00
1.38038E+01	-4.34168E+00
1.44544E+01	-5.31462E+00
1.51356E+01	-6.81462E+00
1.58489E+01	-9.42331E+00
1.65959E+01	-1.50306E+01
1.73780E+01	-3.40111E+01
1.81970E+01	-1.32459E+02
1.90546E+01	-1.62003E+02
1.99526E+01	-1.69176E+02
2.08930E+01	-1.72249E+02
2.18776E+01	-1.73936E+02
2.29087E+01	-1.74995E+02
2.39883E+01	-1.75716E+02
2.51189E+01	-1.76232E+02
2.63027E+01	-1.76614E+02
2.75423E+01	-1.76901E+02
2.88403E+01	-1.77115E+02
3.01995E+01	-1.77270E+02
3.16228E+01	-1.77373E+02
3.31131E+01	-1.77423E+02
3.46737E+01	-1.77417E+02
3.63078E+01	-1.77339E+02
3.80189E+01	-1.77159E+02
3.98107E+01	-1.76813E+02
4.16869E+01	-1.76154E+02
4.36516E+01	-1.74769E+02
4.57088E+01	-1.70958E+02
4.78630E+01	-1.43729E+02
5.01187E+01	-1.73914E+01
5.24807E+01	-8.63856E+00
5.49541E+01	-7.06830E+00
5.75440E+01	-7.87678E+00
6.02560E+01	-1.34591E+01
6.30957E+01	-1.13464E+02
6.60693E+01	-1.69721E+02
6.91831E+01	-1.74080E+02
7.24436E+01	-1.74916E+02
7.58578E+01	-1.73674E+02
7.94328E+01	-1.62543E+02
8.31764E+01	-1.66100E+01
8.70964E+01	-9.25559E+00
9.12011E+01	-1.85368E+01
9.54993E+01	-1.68204E+02
1.00000E+02	-1.76070E+02

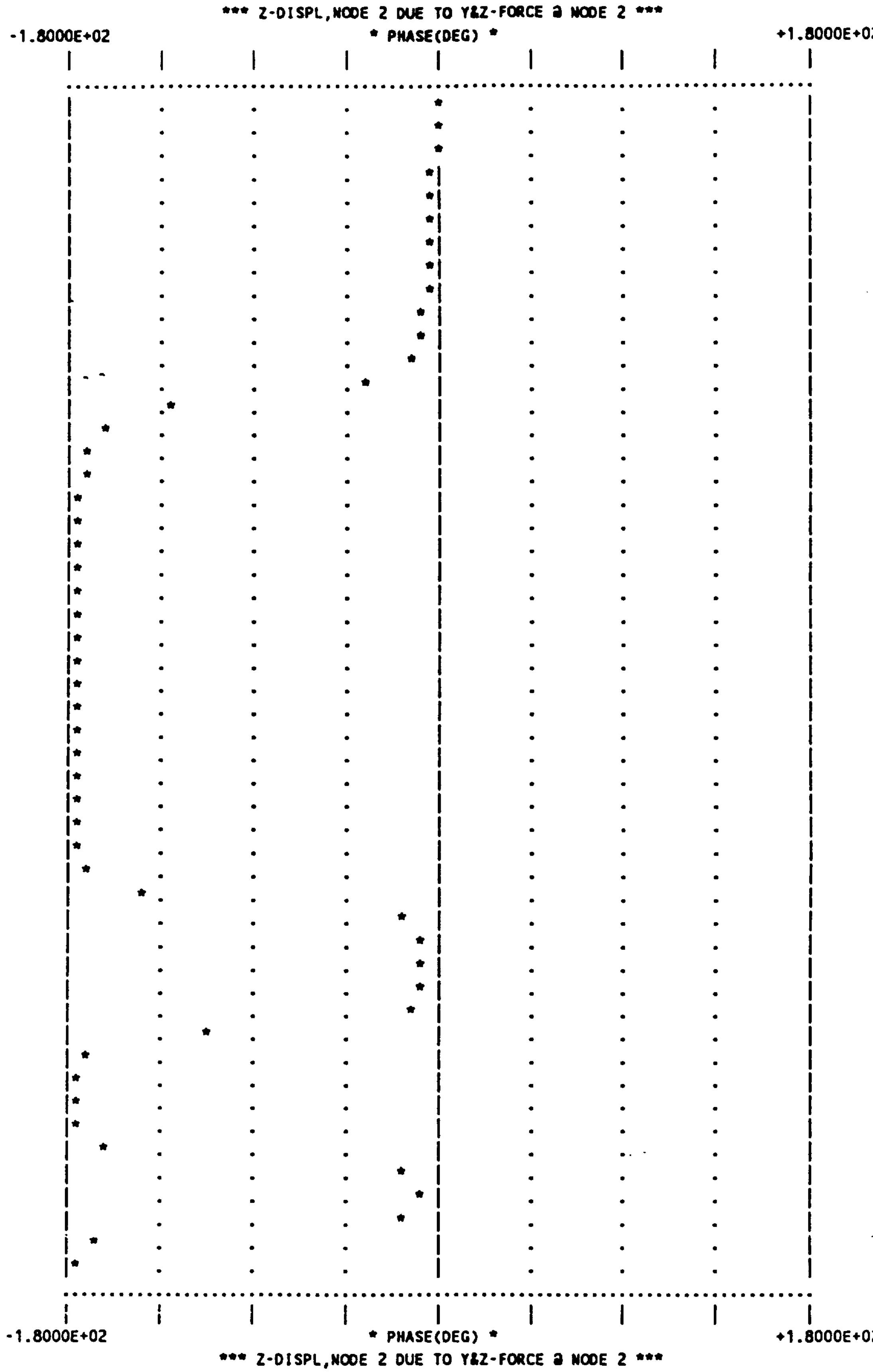


Figure 7b. FRF Phase, LaRC Ten Bay Truss, Z-Displacement/Y and Z-Force at Node 2.

3.2 Fuzzy Classification of Modal Parameters

The methodology currently being developed for evaluating the predictive accuracy of structural dynamic models uses a generic uncertainty model for a class of structures in conjunction with a specific (deterministic) model of a particular structure. The structure-specific model is used to scale a normalized covariance matrix of modal mass and stiffness parameters (the generic uncertainty model) as a means of quantifying the accuracy of predicted modal characteristics and forced response.

The modal parameters upon which the uncertainty model is based consist of all of the elements of the modal mass and stiffness matrices. For a model representing m modes, the modal mass and stiffness matrices are of dimension m x m. Since they are symmetric, there are $N = m^2 + m$ of these modal parameters for a given model. A four mode model would therefore contain 20 modal mass and stiffness parameters.

When applying the vertex method to the evaluation of possibility intervals, computations must be made for 2^N possible combinations of parameters for each FRF at each frequency of interest. For $N = 20$, the number of possible combinations is $2^{20} = 1{,}048{,}576$. Since possibility intervals are only to be evaluated at frequencies near resonance, however, one would expect only a few of the 20 parameters to be significant. Intuitively, these will be the modal mass and stiffness parameters associated with the mode or modes near that resonance. A general means of distinguishing between the significant and insignificant parameters is sought. Methods of "fuzzy classification" have been under investigation for this purpose [1,4].

Reference [1] presented an example of fuzzy classification for a simple 2-DOF system where all six nodal parameters of the two-mode system were considered. The same method has been applied to the first 4 modes of the Ten Bay Truss, the results of which are given below.

This investigation considered different frequency response functions over a range of frequencies spanning the first resonance. Different sets of features were also considered. The

one feature common to all sets is the empirical coefficient of variation of each parameter derived from the statistical analysis of five structures in the Large Space Structures Category [4]. Other features varied over four different sets as follows.

<u>Feature Set 1</u>

- Coefficient of Variation
- Normalized FRF Amplitude Sensitivity

<u>Feature Set 2</u>

- Coefficient of Variation
- Normalized FRF Real Part Sensitivity
- Normalized FRF Imaginary Part Sensitivity

<u>Feature Set 3</u>

- Coefficient of Variation
- Normalized FRF Amplitude Sensitivity, Y Displacement at Node 2
- Normalized FRF Amplitude Sensitivity, Z-Displacement at Node 2

<u>Feature Set 4</u>

- Coefficient of Variation
- Normalized FRF Real Part Sensitivity, Y Displacement at Node 2
- Normalized FRF Imaginary Part Sensitivity, Y-Displacement at Node 2
- Normalized FRF Real Part Sensitivity, Z Displacement at Node 2
- Normalized FRF Imaginary Part Sensitivity, Z-Displacement at Node 2

It is easy to plot the features when there are only two as in the case of Feature Set 1. Sample plots are shown in Figures 8 and 9 for Set 1. In each figure, the features are plotted in 2-D feature space for two excitation frequencies, 14 and 18 Hz. Figure 8 corresponds to the Y-Displacement/Y-Force FRF and Figure 9 corresponds to Z-Displacement/Z-Force. Numerical values for the 18 Hz case of Figure 8 are listed in Table 3.

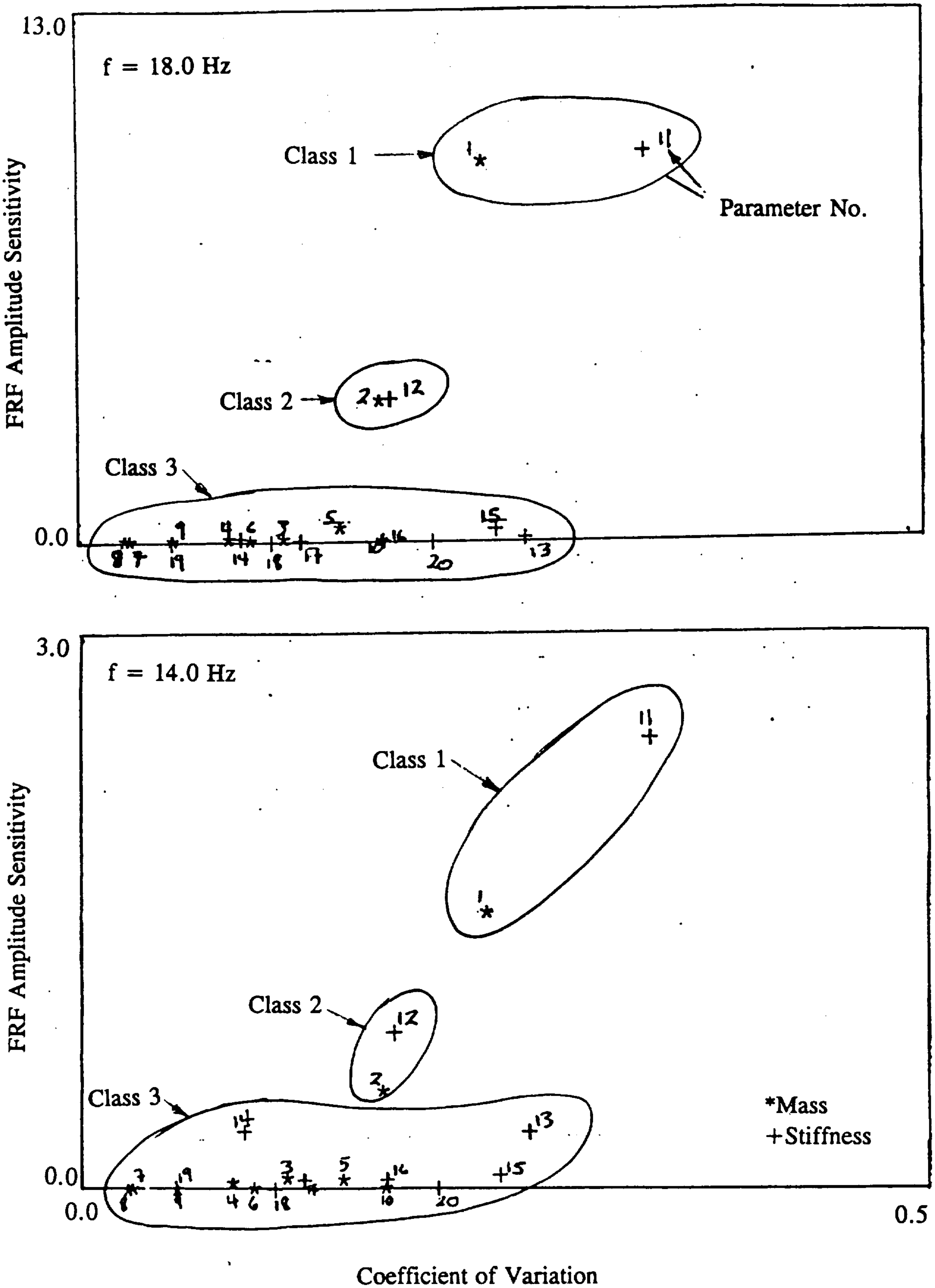
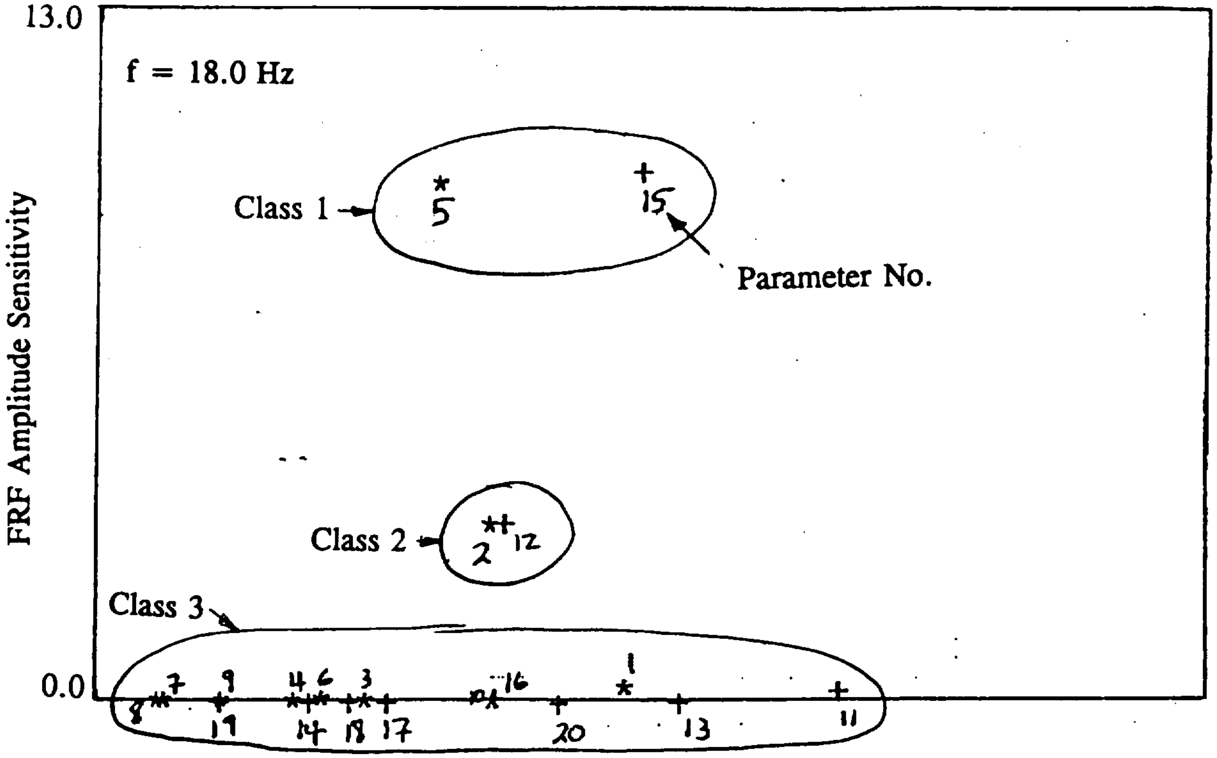


Figure 8. Plots of Model Parameters in Feature Space for Fuzzy Clustering, Y-Displacement/Y-Force.



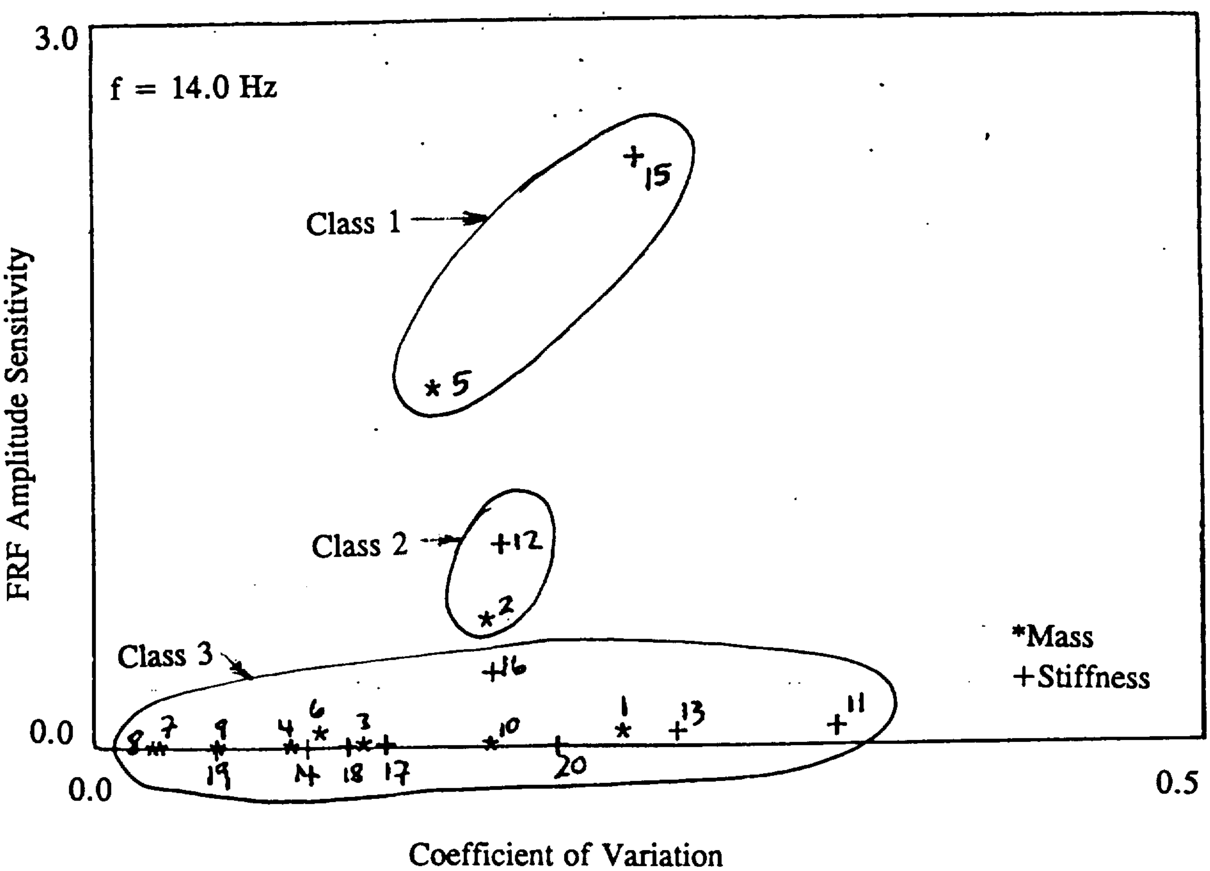


Figure 9. Plots of Model Parameters in Feature Space for Fuzzy Clustering, Z-Displacement/Z-Force.

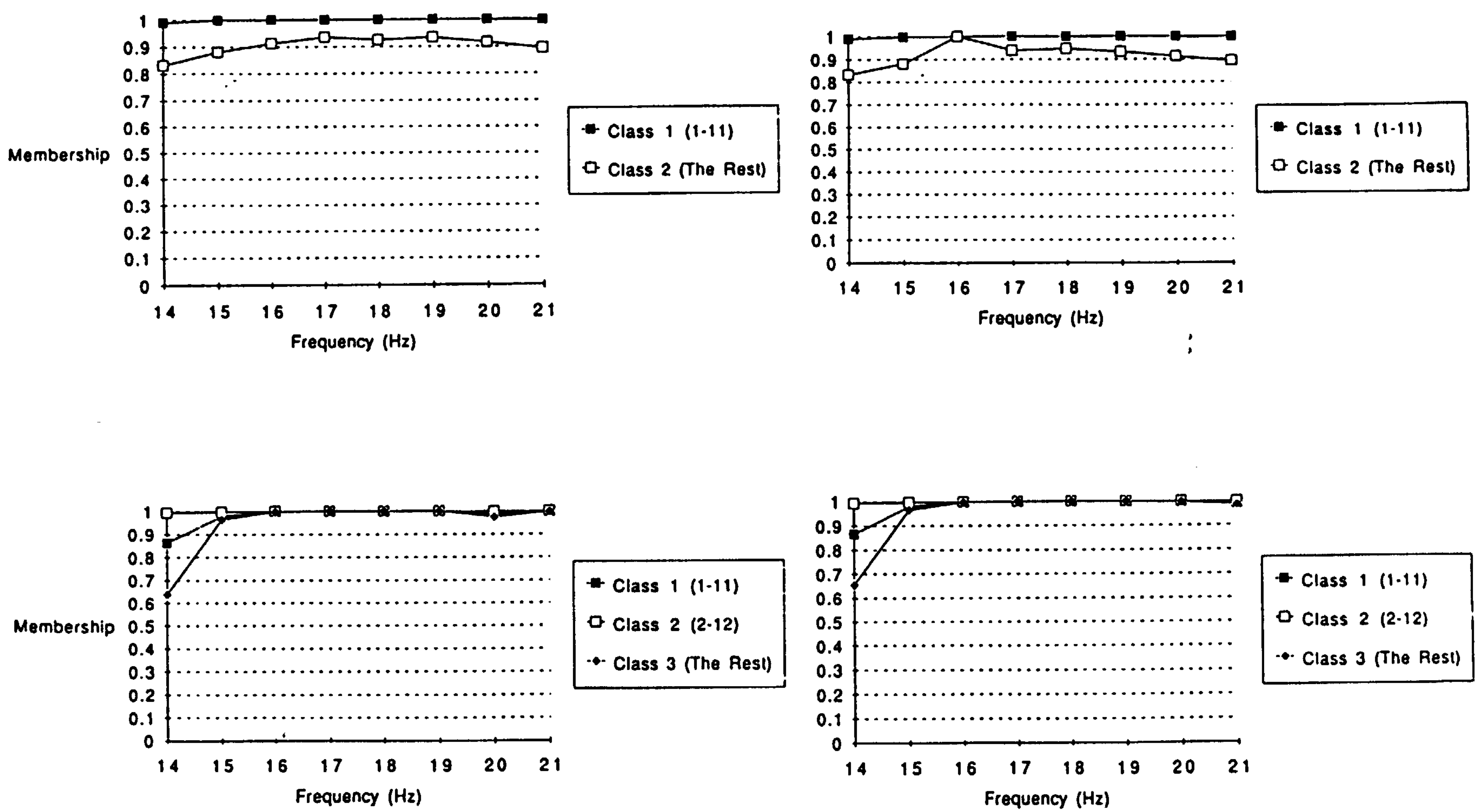
Table 3. Features of Modal Parameters, FRF Amplitude, Y-Displacement/Y-Force at 18 Hz.

Parameter No.	Parameter Symbol	Coefficient of Variation	Normalized Sensitivity
1	m_{11}	.240	9.311
2	m_{12}	.179	3.421
3	m_{13}	.122	.027
4	m_{14}	.090	.018
5	m_{22}	.155	.302
6	m_{23}	.103	.004
7	m_{24}	.031	.003
8	m_{33}	.028	.000
9	m_{34}	.057	.000
10	m_{44}	.180	.000
11	k_{11}	.335	9.581
12	k_{12}	.185	3.513
13	k_{13}	.264	.090
14	k_{14}	.097	.090
15	k_{22}	.247	.426
16	k_{23}	.181	.015
17	k_{24}	.132	.015
18	k_{33}	.115	.000
19	k_{34}	.056	.001
20	k_{44}	.210	.000

Attempts were made to group the parameters into specified numbers of classes for various FRF's and different feature sets. Figures 8 and 9 illustrate the groupings for three classes. When the same data were grouped into two classes, Classes 1 and 2 were combined into Class 1 and Class 3 became Class 2. This turned out to be the case for all of the FRF/feature combinations studied, i.e. Classes 1 and 2 collapsed into a single class when the data were forced into two classes instead of three. However, the classes become more fuzzy when this occurred, i.e. minimum values of parameter memberships in the classes tended to decrease.

Figures 10 through 13 summarize this parametric study, showing the minimum membership of each class plotted as a function of frequency. In all cases, membership is greatest near resonance (approximately 18 Hz for the first set of bending modes). Membership is seen to drop off as the excitation frequency gets further away from resonance. Membership also tends to increase as the number of classes increases. Clearly in the limit as the number of classes equals the number of data points (parameters) each class will have the maximum membership of unity.

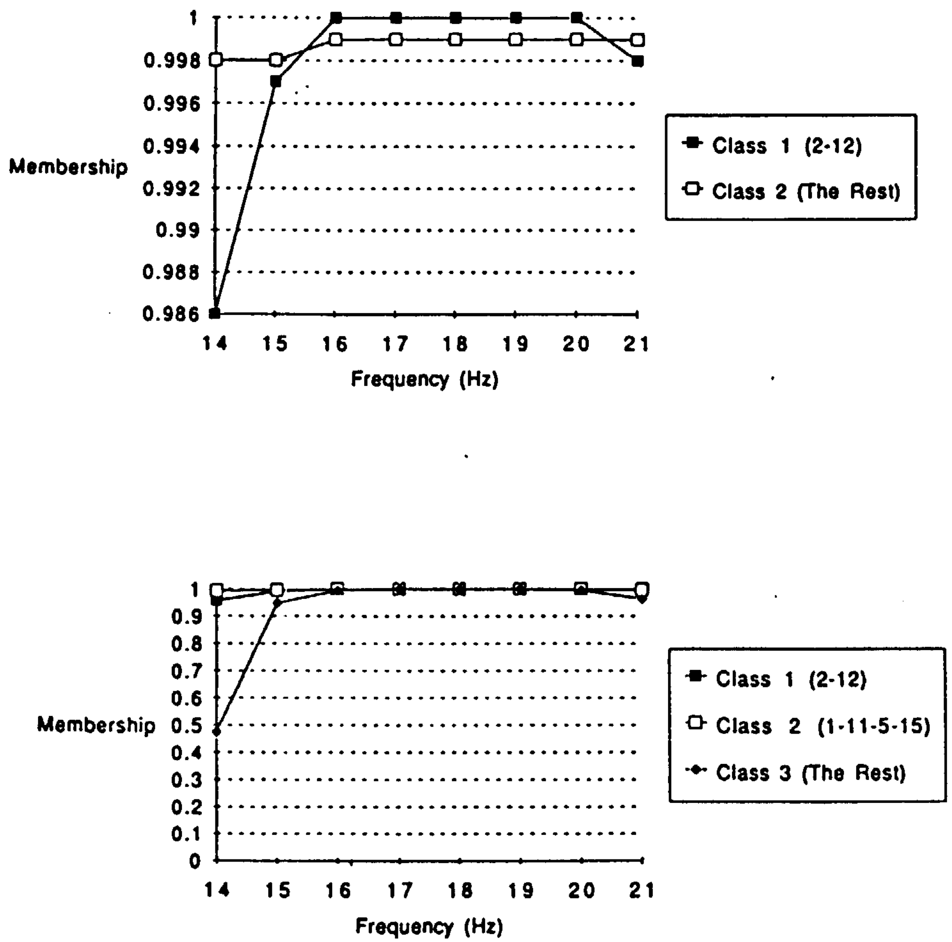
The most important conclusion to draw from this investigation is that the number of significant parameters for purposes of evaluating FRF uncertainty tends to diminish to a very small number in the neighborhood of resonance where the first order statistical method breaks down. This implies that the fuzzy set approach for bounding uncertainties in these regions should be computationally efficient.



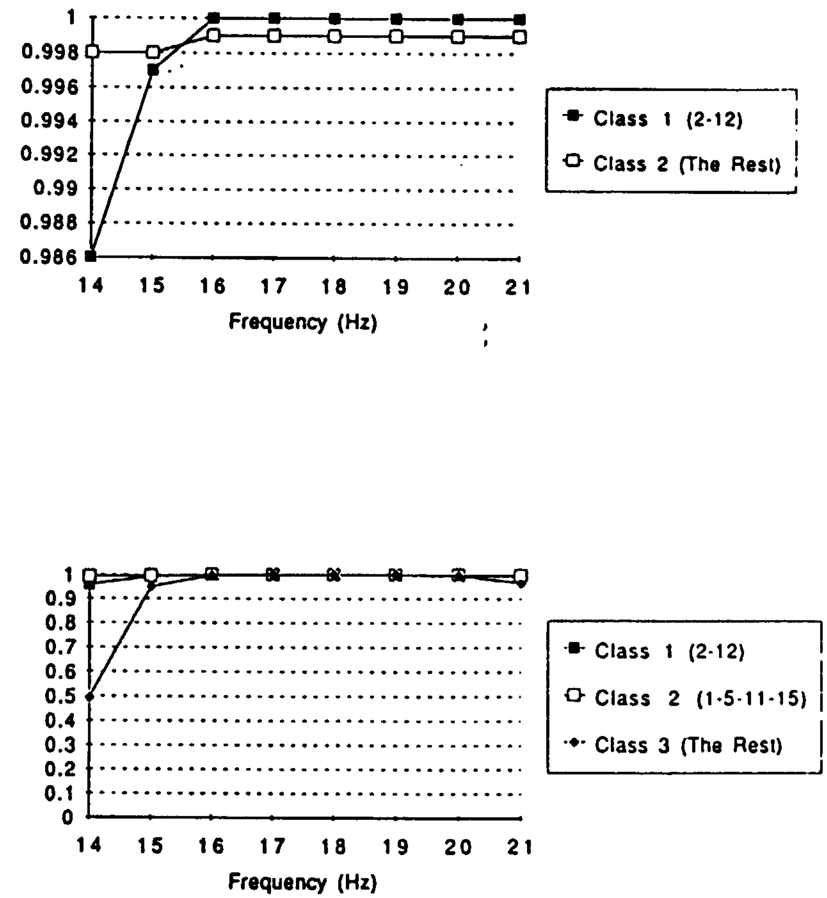
(a) Two Features: Parameter C.O.V. and FRF Amplitude

(b) Three Features: Parameter C.O.V. and FRF Real and Imaginary

Figure 10. Fuzzy Classification of Modal Mass and Stiffness Parameters for Computing FRF Uncertainty of the LaRC Ten Bay Truss Near Resonance, Y-Displacement/Y-Force at Node 2.

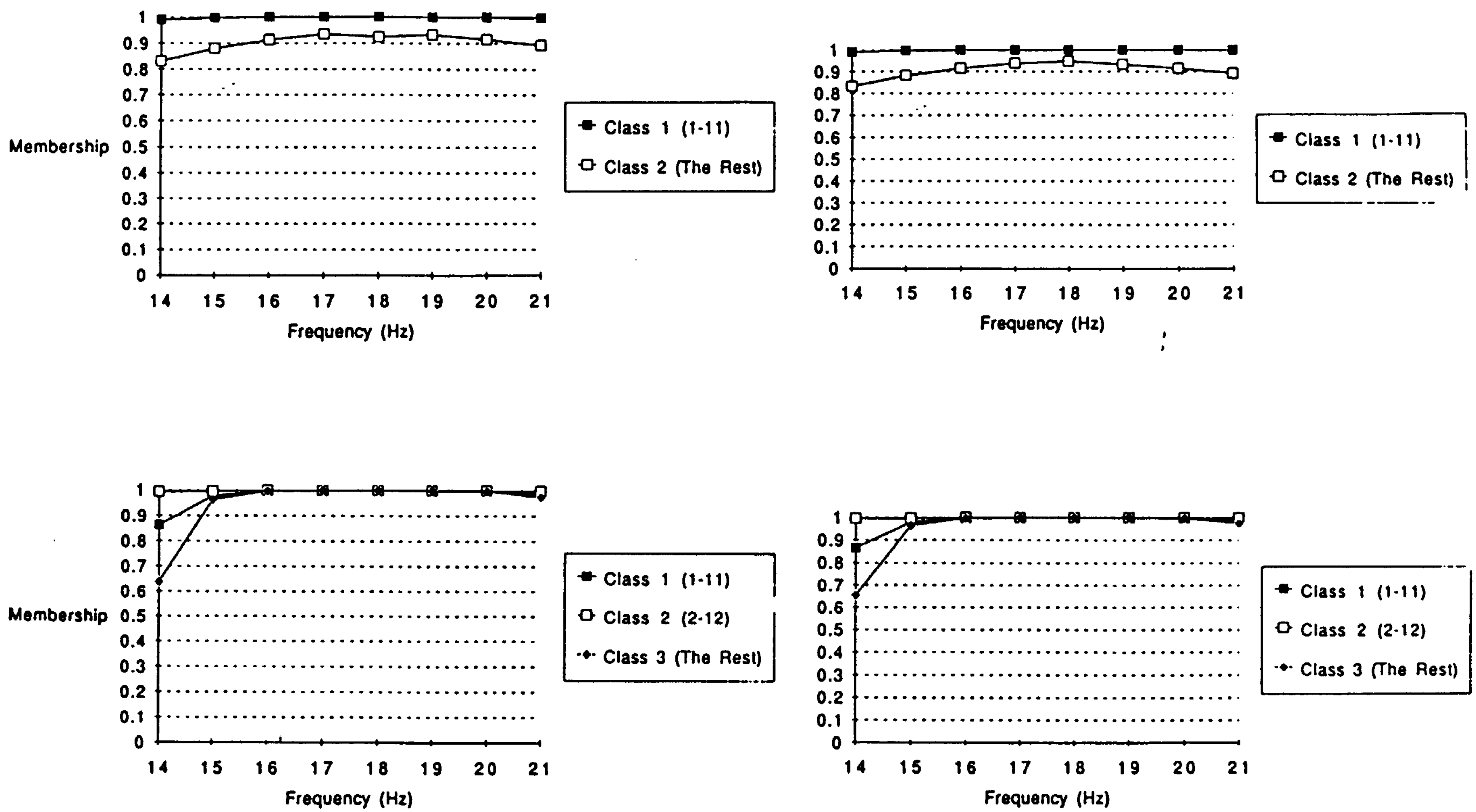


(a) Two Features: Parameter C.O.V. and FRF Amplitude



(b) Three Features: Parameter C.O.V. and FRF Real and Imaginary

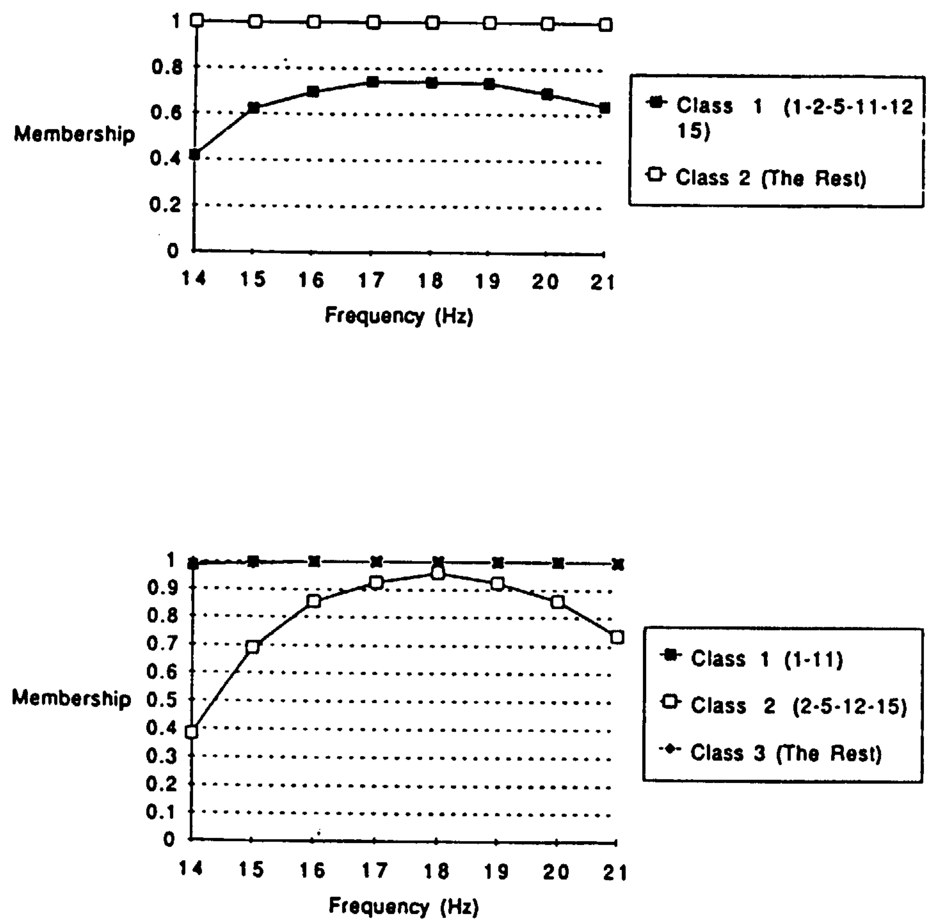
Figure 11. Fuzzy Classification of Modal Mass and Stiffness Parameters for Computing FRF Uncertainty of the LaRC Ten Bay Truss Near Resonance, Z-Displacement/Y-Force at Node 2.



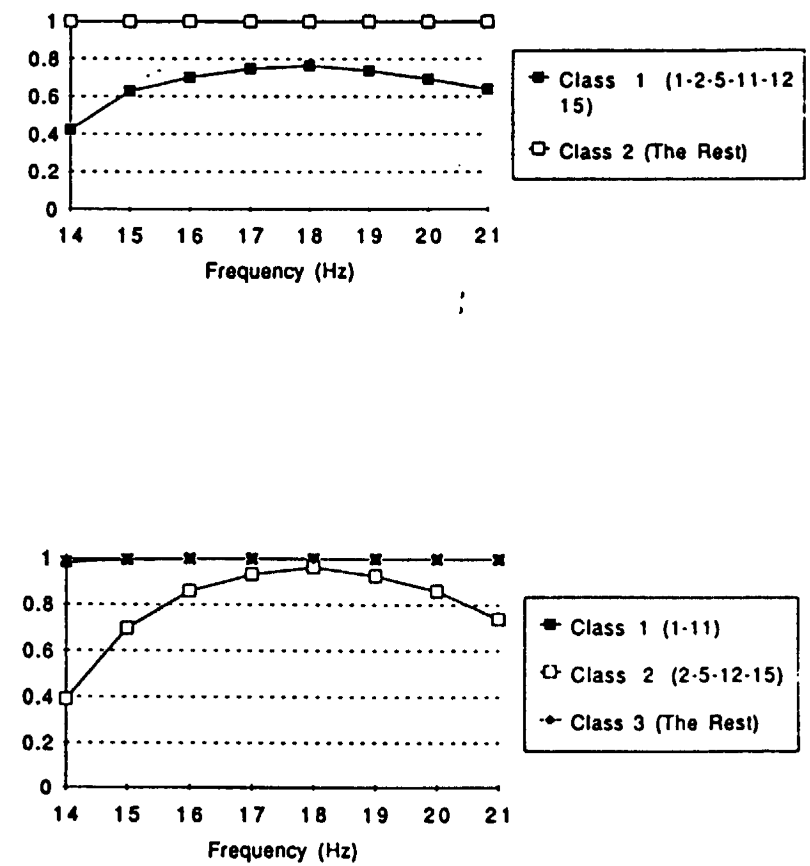
(a) Two Features: Parameter C.O.V. and FRF Amplitude

(b) Three Features: Parameter C.O.V. and FRF Real and Imaginary

Figure 12. Fuzzy Classification of Modal Mass and Stiffness Parameters for Computing FRF Uncertainty of the LaRC Ten Bay Truss Near Resonance, Y-Displacement/Y and Z-Force at Node 2.



(a) Three Features: Parameter C.O.V. and FRF Amplitude, X and Y



(b) Five Features: Parameter C.O.V. and FRF Real and Imaginary, X and Y

Figure 13. Fuzzy Classification of Modal Mass and Stiffness Parameters for Computing FRF Uncertainty of the LaRC Ten Bay Truss Near Resonance, Y and Z-Displacement/Y and Z-Force at Node 2.

4. ANALYSIS AND CONCLUSIONS

4.1 Interpretation of Results

This report has focused on the investigation of fuzzy set methods for bounding the uncertainty of structural response near resonance. The results of using a fuzzy classification method to identify the parameters of a model which contribute significantly to response uncertainty indicate that when modeling uncertainty is expressed in terms of modal parameters, only a few parameters associated with the modes near a resonance will contribute to response uncertainty.

This is an important conclusion in that it should make it possible to establish upper bounds on response uncertainty near resonance where linearized methods of covariance propagation break down.

4.2 Relationship to Research Objectives

Further work is needed to implement the fuzzy set method. The fuzzy classification method minimizes the number of parameters which must be included in computations involving the vertex method for bounding response uncertainty. The second part of the problem, as discussed in Section 3.1, is to determine whether any extrema exist within the parameter space defined by all possible combinations of upper and lower bounds on parameter intervals, and if so, what their values are. This part of the investigation continues.

4.3 Work Planned for the Seventh Quarter

A revised schedule for the remainder of the contract period will be prepared early in the seventh quarter when the visibility on other EMA projects improves. It is presently anticipated that a no-cost extension of the present contract period will be requested.

REFERENCES

1. Hasselman, T.K. and Chrostowski, J.D., "Methods for Evaluating the Predictive Accuracy of Structure Dynamic Models," EMA Technical Report No. TR-89-1152-5 prepared for NASA, September, 1990.

2. Hasselman, T.K. and Chrostowski, J.D., "Methods for Evaluating the Predictive Accuracy of Structural Dynamic Models," EMA Technical Report No. 88-1146-1 prepared for NASA, August, 1988.

3. Dong, W. and Shah, H., "Vertex Method for Computing Function of Fuzzy Variables," International Journal of Fuzzy Sets and Systems, to appear in 1989.

4. Hasselman, T.K., "Methods for Evaluating the Predictive Accuracy of Structural Dynamic Models," EMA Technical Report No. TR-89-1152-4 prepared for NASA, June, 1990.

APPENDIX:

Graphical Output for Analysis-Test Correlation of the LaRC Ten Bay Truss

```
*** MODAL MODEL OF NASA/LANGLEY TEN BAY TRUSS ***
          ** DOUBLE PRECISION **
    ** FREQ AND EIGENVECTOR ESTIMATION RUN **
    ANALYST = J.D. CHROSTOWSKI  DATE = 9/21/90
 TEST FREQUENCY DATA EXTRACTED BY ERA REALIZATION


                 *****************************
                 *** SYSTEM ANALYSIS DATA ***
                 *****************************

        DATA ANALYZED = EIGEN-PARAMETER ANALYSIS
        ESTIMATOR USED = BAYESIAN ESTIMATION (MORE DATA THAN PARMS)
        DERIVATIVE METHOD = MODAL EXPANSION USED TO CALC DERIVATIVES
        # ROOTS EXTRACTED =  15
        # ROOTS USED FOR RESP/SENS CALCS =  15
        # OF DATA BATCHES USED =  1
        STEP SIZED USED FOR EST = 100.0%
```

```
                 ***************************
                 ** TEST DATA INFORMATION **
                      (DATA BATCH # 1)
                 ***************************


               ============================
               === FREQ DATA, TEST SET #1 ===
               ============================

      FREQ FILENAME = /usr/people/jon/ssid/tbt/ftest.dat
      FREQ FORMAT   = (F10.0)

               FREQ   TEST   TEST FREQ  MODEL
               OBS #  MODE #   COV(%)   MODE #
                 1      1       2.00      2
                 2      2       2.00      1
                 3      3       2.00      3
                 4      4       2.00      4
                 5      5       2.00      5
                 6      6       2.00      6
                 7      7       2.00      7
                 8      8       2.00      8
                 9      9       2.00      9


            ===================================
            === EIGENVECTOR DATA, TEST SET # 1 ===
            ===================================


      VECTOR FILENAME     = /usr/people/jon/ssid/tbt/tbt.eig
      VECTOR FORMAT       = (I2,6(1X,1PE12.5))
      # OF TEST MODES USED=   6


                  TEST MODE #  1 / MODEL MODE #  2
                  ++++++++++++++++++++++++++++++
-------------------------------------------------------------------------------
 VECT  SENSOR  SENS  COV(%)  | MODEL  MODEL  MODEL |      RESPONSE
 OBS #   ID    DIRCT         | COMP   NODE    DOF  |     DESCRIPTION
-------------------------------------------------------------------------------
   1      2     2    20.00   |  1        2     2   | Y-MOTION @ NODE 2
   2      2     3    20.00   |  1        2     3   | Z-MOTION @ NODE 2
   3     22     2    20.00   |  1       22     2   | Y-MOTION @ NODE 22
   4     22     3    20.00   |  1       22     3   | Z-MOTION @ NODE 22


                  TEST MODE #  2 / MODEL MODE #  1
                  ++++++++++++++++++++++++++++++
-------------------------------------------------------------------------------
 VECT  SENSOR  SENS  COV(%)  | MODEL  MODEL  MODEL |      RESPONSE
 OBS #   ID    DIRCT         | COMP   NODE    DOF  |     DESCRIPTION
-------------------------------------------------------------------------------
   5      2     2    20.00   |  1        2     2   | Y-MOTION @ NODE 2
   6      2     3    20.00   |  1        2     3   | Z-MOTION @ NODE 2
   7     22     2    20.00   |  1       22     2   | Y-MOTION @ NODE 22
   8     22     3    20.00   |  1       22     3   | Z-MOTION @ NODE 22
```

TEST MODE # 4 / MODEL MODE # 4

+++++++++++++++++++++++++++++++

VECT OBS #	SENSOR ID	SENS DIRCT	COV(%)	MODEL COMP	MODEL NODE	MODEL DOF	RESPONSE DESCRIPTION
9	2	2	20.00	1	2	2	Y-MOTION @ NODE 2
10	2	3	20.00	1	2	3	Z-MOTION @ NODE 2
11	22	2	20.00	1	22	2	Y-MOTION @ NODE 22
12	22	3	20.00	1	22	3	Z-MOTION @ NODE 22

TEST MODE # 5 / MODEL MODE # 5

+++++++++++++++++++++++++++++++

VECT OBS #	SENSOR ID	SENS DIRCT	COV(%)	MODEL COMP	MODEL NODE	MODEL DOF	RESPONSE DESCRIPTION
13	2	2	20.00	1	2	2	Y-MOTION @ NODE 2
14	2	3	20.00	1	2	3	Z-MOTION @ NODE 2
15	22	2	20.00	1	22	2	Y-MOTION @ NODE 22
16	22	3	20.00	1	22	3	Z-MOTION @ NODE 22

TEST MODE # 8 / MODEL MODE # 8

+++++++++++++++++++++++++++++++

VECT OBS #	SENSOR ID	SENS DIRCT	COV(%)	MODEL COMP	MODEL NODE	MODEL DOF	RESPONSE DESCRIPTION
17	2	2	20.00	1	2	2	Y-MOTION @ NODE 2
18	2	3	20.00	1	2	3	Z-MOTION @ NODE 2
19	22	2	20.00	1	22	2	Y-MOTION @ NODE 22
20	22	3	20.00	1	22	3	Z-MOTION @ NODE 22

TEST MODE # 9 / MODEL MODE # 9

+++++++++++++++++++++++++++++++

VECT OBS #	SENSOR ID	SENS DIRCT	COV(%)	MODEL COMP	MODEL NODE	MODEL DOF	RESPONSE DESCRIPTION
21	2	2	20.00	1	2	2	Y-MOTION @ NODE 2
22	2	3	20.00	1	2	3	Z-MOTION @ NODE 2
23	22	2	20.00	1	22	2	Y-MOTION @ NODE 22
24	22	3	20.00	1	22	3	Z-MOTION @ NODE 22

==
= TEST DATA vs INITIAL MODEL RESPONSE-DATA BATCH # 1 =
==

****
*** SYSTEM EIGENVALUES ***
****

MODE NO.	ORIG MODEL FREQ (Hz)	REVISED MODEL FREQ (Hz)	TEST FREQ (Hz)	ORIG DIFF(%)	PREV CYC DIFF(%)	CURR CYC DIFF(%)
1	1.78857D+01	-----------	1.80480D+01	0.90	------	------
2	1.78868D+01	-----------	1.80400D+01	0.85	------	------
3	6.28527D+01	-----------	6.80430D+01	7.63	------	------
4	9.30754D+01	-----------	9.16340D+01	-1.57	------	------
5	9.31229D+01	-----------	9.26090D+01	-0.55	------	------
6	1.68636D+02	-----------	1.60765D+02	-4.90	------	------
7	1.87045D+02	-----------	1.92537D+02	2.85	------	------
8	2.13381D+02	-----------	2.00154D+02	-6.61	------	------
9	2.13732D+02	-----------	2.00195D+02	-6.76	------	------
10	3.01045D+02	-----------	*Not Used*	------	------	------
11	3.37506D+02	-----------	*Not Used*	------	------	------
12	3.39022D+02	-----------	*Not Used*	------	------	------
13	4.02043D+02	-----------	*Not Used*	------	------	------
14	4.51529D+02	-----------	*Not Used*	------	------	------
15	4.55580D+02	-----------	*Not Used*	------	------	------

= TEST DATA vs REVISED MODEL RESPONSE-DATA BATCH # 1, AFTER EST CYCLE # 9 =

****
*** SYSTEM EIGENVALUES ***
****

MODE NO.	ORIG MODEL FREQ (Hz)	REVISED MODEL FREQ (Hz)	TEST FREQ (Hz)	ORIG DIFF(%)	PREV CYC DIFF(%)	CURR CYC DIFF(%)
1	1.78857D+01	1.78480D+01	1.80480D+01	0.90	1.11	1.11
2	1.78868D+01	1.78521D+01	1.80400D+01	0.85	1.04	1.04
3	6.28527D+01	6.52003D+01	6.80430D+01	7.63	4.18	4.18
4	9.30754D+01	9.06531D+01	9.16340D+01	-1.57	1.07	1.07
5	9.31229D+01	9.07120D+01	9.26090D+01	-0.55	2.05	2.05
6	1.68636D+02	1.66678D+02	1.60765D+02	-4.90	-3.68	-3.68
7	1.87045D+02	1.93759D+02	1.92537D+02	2.85	-0.63	-0.63
8	2.13381D+02	2.04251D+02	2.00154D+02	-6.61	-2.05	-2.05
9	2.13732D+02	2.04551D+02	2.00195D+02	-6.76	-2.18	-2.18
10	3.01045D+02	3.21219D+02	*Not Used*	------	------	------
11	3.37506D+02	3.34299D+02	*Not Used*	------	------	------
12	3.39022D+02	3.35534D+02	*Not Used*	------	------	------
13	4.02043D+02	4.31925D+02	*Not Used*	------	------	------
14	4.51529D+02	4.48435D+02	*Not Used*	------	------	------
15	4.55580D+02	4.52209D+02	*Not Used*	------	------	------

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****************************************
*** EIGENVECTORS IN X-COORDINATES ***
***   -NORMALIZED TO UNIT MASS-   ***
* (Only Test Data Coordinates Shown)*
****************************************
```

*** TEST MODE NO. 1 vs ANALYSIS MODE NO. 2 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	2.8328D+00	2.1866D+00	3.0243D+00	6.33	27.70	27.70	Y-MOTION @ NODE 2
1	2	Z	-4.9399D+00	-5.3245D+00	-5.2955D+00	6.71	-0.55	-0.55	Z-MOTION @ NODE 2
1	22	Y	1.0295D+00	7.7434D-01	9.6492D-01	-6.69	19.75	19.75	Y-MOTION @ NODE 22
1	22	Z	-1.7198D+00	-1.7702D+00	-1.7051D+00	-0.86	-3.82	-3.82	Z-MOTION @ NODE 22

*** TEST MODE NO. 2 vs ANALYSIS MODE NO. 1 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	4.9406D+00	5.3260D+00	5.5342D+00	10.73	3.76	3.76	Y-MOTION @ NODE 2
1	2	Z	2.8320D+00	2.1860D+00	1.8323D+00	-54.56	-19.30	-19.30	Z-MOTION @ NODE 2
1	22	Y	1.7193D+00	1.7700D+00	1.8615D+00	7.64	4.92	4.92	Y-MOTION @ NODE 22
1	22	Z	1.0293D+00	7.7372D-01	7.0444D-01	-46.12	-9.83	-9.84	Z-MOTION @ NODE 22

*** TEST MODE NO. 4 vs ANALYSIS MODE NO. 4 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	3.1266D+00	2.7922D+00	2.9920D+00	-4.50	6.68	6.68	Y-MOTION @ NODE 2
1	2	Z	3.5464D+00	3.3125D+00	3.5073D+00	-1.12	5.55	5.55	Z-MOTION @ NODE 2
1	22	Y	-2.7924D+00	-2.6308D+00	-2.0135D+00	-38.69	-30.66	-30.66	Y-MOTION @ NODE 22
1	22	Z	-3.0536D+00	-3.0397D+00	-3.4583D+00	11.70	12.10	12.10	Z-MOTION @ NODE 22

*** TEST MODE NO. 5 vs ANALYSIS MODE NO. 5 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	3.5677D+00	3.3304D+00	2.7612D+00	-29.21	-20.62	-20.62	Y-MOTION @ NODE 2
1	2	Z	-3.1116D+00	-2.7808D+00	-2.8070D+00	-10.85	0.93	0.93	Z-MOTION @ NODE 2
1	22	Y	-3.0328D+00	-3.0250D+00	-2.8993D+00	-4.61	-4.34	-4.34	Y-MOTION @ NODE 22
1	22	Z	2.8109D+00	2.6399D+00	2.1911D+00	-28.29	-20.48	-20.48	Z-MOTION @ NODE 22

*** TEST MODE NO. 8 vs ANALYSIS MODE NO. 8 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	-1.2221D+00	-1.5156D+00	-5.3383D+00	77.11	71.61	71.61	Y-MOTION @ NODE 2
1	2	Z	-3.8221D+00	-3.8831D+00	-3.7198D+00	-2.75	-4.39	-4.39	Z-MOTION @ NODE 2
1	22	Y	1.3726D-01	4.6843D-01	2.1146D+00	93.51	77.85	77.85	Y-MOTION @ NODE 22

1	22	Z	1.8974D-01	8.8540D-01	1.7281D+00	89.02	48.77	48.76	Z-MOTION @ NODE 22

*** TEST MODE NO. 9 vs ANALYSIS MODE NO. 9 for TEST SETUP NO. 1 ***

COMP NO.	NODE NO.	DOF	ORIG MODEL VECTOR	REVISED MODEL VECTOR	TEST VECTOR	ORIG DIFF(%)	PREV DIFF(%)	CURR DIFF(%)	COORDINATE DESCRIPTION
1	2	Y	3.9391D+00	3.9868D+00	5.1438D+00	23.42	22.49	22.49	Y-MOTION @ NODE 2
1	2	Z	-1.1948D+00	-1.4835D+00	-2.3518D+00	49.20	36.93	36.92	Z-MOTION @ NODE 2
1	22	Y	-1.8277D-01	-8.4989D-01	-9.7691D-01	81.29	13.00	13.00	Y-MOTION @ NODE 22
1	22	Z	1.4997D-01	4.9975D-01	6.3808D-01	76.50	21.68	21.68	Z-MOTION @ NODE 22

```
                                    ******************************************
                                    *** TEST FREQ #  1 vs. ANAL FREQ #  2 ***
                                    ***    % Diff Between Anal & Test     ***
                                    ***   (Test Freq =  1.80400E+01 Hz)   ***
                                    ******************************************
                    -5.0000E+00                         0.0000E+00                             5.0000E+00
                          |        |        |        |        |        |        |        |        |
CYCLE#   ANAL FREQ    PCT DIFF  .................................................................................
 ---    1.78868E+01  8.48957E-01  .        .        .        .        ********  .        .        .        .
  1     1.77049E+01  1.85782E+00  .        .        .        .        ****************   .        .        .
  2     1.78324E+01  1.15080E+00  .        .        .        .        **********.        .        .        .
  3     1.78503E+01  1.05133E+00  .        .        .        .        ********* .        .        .        .
  4     1.78502E+01  1.05205E+00  .        .        .        .        ********* .        .        .        .
  5     1.78519E+01  1.04278E+00  .        .        .        .        ********* .        .        .        .
  6     1.78519E+01  1.04268E+00  .        .        .        .        ********* .        .        .        .
  7     1.78521E+01  1.04149E+00  .        .        .        .        ********* .        .        .        .
  8     1.78521E+01  1.04147E+00  .        .        .        .        ********* .        .        .        .
  9     1.78521E+01  1.04132E+00  .        .        .        .        ********* .        .        .        .
                              .................................................................................
                          |        |        |        |        |        |        |        |        |
                    -5.0000E+00                         0.0000E+00                             5.0000E+00
```

```
                                    ******************************************
                                    *** TEST FREQ #  2 vs. ANAL FREQ #  1 ***
                                    ***    % Diff Between Anal & Test     ***
                                    ***   (Test Freq =  1.80480E+01 Hz)   ***
                                    ******************************************
                    -5.0000E+00                         0.0000E+00                             5.0000E+00
                          |        |        |        |        |        |        |        |        |
CYCLE#   ANAL FREQ    PCT DIFF  .................................................................................
 ---    1.78857E+01  8.99181E-01  .        .        .        .        ********  .        .        .        .
  1     1.77007E+01  1.92458E+00  .        .        .        .        ****************   .        .        .
  2     1.78284E+01  1.21673E+00  .        .        .        .        ***********        .        .        .
  3     1.78462E+01  1.11787E+00  .        .        .        .        **********.        .        .        .
  4     1.78461E+01  1.11854E+00  .        .        .        .        **********.        .        .        .
  5     1.78478E+01  1.10935E+00  .        .        .        .        **********.        .        .        .
  6     1.78478E+01  1.10925E+00  .        .        .        .        **********.        .        .        .
  7     1.78480E+01  1.10807E+00  .        .        .        .        **********.        .        .        .
  8     1.78480E+01  1.10805E+00  .        .        .        .        **********.        .        .        .
  9     1.78480E+01  1.10790E+00  .        .        .        .        **********.        .        .        .
                              .................................................................................
                          |        |        |        |        |        |        |        |        |
                    -5.0000E+00                         0.0000E+00                             5.0000E+00
```

```
                                                       *****************************************
                                                       *** TEST FREQ #  3 vs. ANAL FREQ #  3 ***
                                                       ***    % Diff Between Anal & Test     ***
                                                       ***   (Test Freq =  6.80430E+01 Hz)   ***
                                                       *****************************************
                              -1.0000E+01                             0.0000E+00                              1.0000E+01
                                   |         |         |         |         |         |         |         |         |
CYCLE#   ANAL FREQ     PCT DIFF    .................................................................................
  ---    6.28527E+01   7.62796E+00 .         .         .         .         ********************************        .
   1     6.43686E+01   5.40011E+00 .         .         .         .         ***********************       .         .
   2     6.51276E+01   4.28466E+00 .         .         .         .         ******************  .         .         .
   3     6.52244E+01   4.14244E+00 .         .         .         .         ******************  .         .         .
   4     6.52007E+01   4.17727E+00 .         .         .         .         ******************  .         .         .
   5     6.52044E+01   4.17181E+00 .         .         .         .         ******************  .         .         .
   6     6.52004E+01   4.17763E+00 .         .         .         .         ******************  .         .         .
   7     6.52008E+01   4.17707E+00 .         .         .         .         ******************  .         .         .
   8     6.52003E+01   4.17785E+00 .         .         .         .         ******************  .         .         .
   9     6.52003E+01   4.17778E+00 .         .         .         .         ******************  .         .         .
                                   .................................................................................
                                   |         |         |         |         |         |         |         |         |
                              -1.0000E+01                             0.0000E+00                              1.0000E+01

                                                       *****************************************
                                                       *** TEST FREQ #  4 vs. ANAL FREQ #  4 ***
                                                       ***    % Diff Between Anal & Test     ***
                                                       ***   (Test Freq =  9.16340E+01 Hz)   ***
                                                       *****************************************
                              -5.0000E+00                             0.0000E+00                              5.0000E+00
                                   |         |         |         |         |         |         |         |         |
CYCLE#   ANAL FREQ     PCT DIFF    .................................................................................
  ---    9.30754E+01  -1.57304E+00 .         .         .      **************         .         .         .         .
   1     8.99876E+01   1.79673E+00 .         .         .         .         ***************     .         .         .
   2     9.07305E+01   9.85992E-01 .         .         .         .         ********* .         .         .         .
   3     9.06881E+01   1.03222E+00 .         .         .         .         ********* .         .         .         .
   4     9.06629E+01   1.05972E+00 .         .         .         .         ********* .         .         .         .
   5     9.06581E+01   1.06504E+00 .         .         .         .         **********.         .         .         .
   6     9.06543E+01   1.06912E+00 .         .         .         .         **********.         .         .         .
   7     9.06537E+01   1.06982E+00 .         .         .         .         **********.         .         .         .
   8     9.06532E+01   1.07037E+00 .         .         .         .         **********.         .         .         .
   9     9.06531E+01   1.07046E+00 .         .         .         .         **********.         .         .         .
                                   .................................................................................
                                   |         |         |         |         |         |         |         |         |
                              -5.0000E+00                             0.0000E+00                              5.0000E+00
```

```
                                                      *******************************************
                                                      *** TEST FREQ #  5 vs. ANAL FREQ #  5 ***
                                                      ***    % Diff Between Anal & Test     ***
                                                      ***   (Test Freq =  9.26090E+01 Hz)   ***
                                                      *******************************************
                              -5.0000E+00                             0.0000E+00                               5.0000E+00
                                   |         |         |         |         |         |         |         |         |
CYCLE#  ANAL FREQ    PCT DIFF      .................................................................................
  ---   9.31229E+01  -5.54930E-01  .         .         .         .     *****         .         .         .         .
   1    9.00470E+01   2.76649E+00  .         .         .         .         ***********************       .         .
   2    9.07888E+01   1.96551E+00  .         .         .         .         *****************   .         .         .
   3    9.07470E+01   2.01056E+00  .         .         .         .         *****************   .         .         .
   4    9.07217E+01   2.03788E+00  .         .         .         .         *****************   .         .         .
   5    9.07169E+01   2.04305E+00  .         .         .         .         *****************   .         .         .
   6    9.07132E+01   2.04710E+00  .         .         .         .         *****************   .         .         .
   7    9.07126E+01   2.04778E+00  .         .         .         .         *****************   .         .         .
   8    9.07121E+01   2.04832E+00  .         .         .         .         *****************   .         .         .
   9    9.07120E+01   2.04841E+00  .         .         .         .         *****************   .         .         .
                                   .................................................................................
                                   |         |         |         |         |         |         |         |         |
                              -5.0000E+00                             0.0000E+00                               5.0000E+00
```

```
                                                      *******************************************
                                                      *** TEST FREQ #  6 vs. ANAL FREQ #  6 ***
                                                      ***    % Diff Between Anal & Test     ***
                                                      ***   (Test Freq =  1.60765E+02 Hz)   ***
                                                      *******************************************
                              -5.0000E+00                             0.0000E+00                               5.0000E+00
                                   |         |         |         |         |         |         |         |         |
CYCLE#  ANAL FREQ    PCT DIFF      .................................................................................
  ---   1.68636E+02  -4.89591E+00  .****************************************         .         .         .         .
   1    1.64758E+02  -2.48387E+00  .         .         *********************         .         .         .         .
   2    1.66553E+02  -3.60052E+00  .         .******************************         .         .         .         .
   3    1.66655E+02  -3.66372E+00  .         .******************************         .         .         .         .
   4    1.66664E+02  -3.66933E+00  .         .******************************         .         .         .         .
   5    1.66675E+02  -3.67601E+00  .         .******************************         .         .         .         .
   6    1.66676E+02  -3.67666E+00  .         .******************************         .         .         .         .
   7    1.66677E+02  -3.67754E+00  .         .******************************         .         .         .         .
   8    1.66677E+02  -3.67763E+00  .         .******************************         .         .         .         .
   9    1.66678E+02  -3.67774E+00  .         .******************************         .         .         .         .
                                   .................................................................................
                                   |         |         |         |         |         |         |         |         |
                              -5.0000E+00                             0.0000E+00                               5.0000E+00
```

```
                                        ******************************************
                                        *** TEST FREQ #  7 vs. ANAL FREQ #  7 ***
                                        ***    % Diff Between Anal & Test     ***
                                        ***   (Test Freq =  1.92537E+02 Hz)   ***
                                        ******************************************
                        -5.0000E+00                        0.0000E+00                        5.0000E+00
                             |      |      |      |      |      |      |      |      |
CYCLE#   ANAL FREQ    PCT DIFF   .........................................................
 ---    1.87045E+02  2.85227E+00  .      .      .      .      *************************   .      .
  1     1.91702E+02  4.33917E-01  .      .      .      .      ****    .      .      .      .
  2     1.93713E+02 -6.10605E-01  .      .      .      .   ******     .      .      .      .
  3     1.93700E+02 -6.03927E-01  .      .      .      .   ******     .      .      .      .
  4     1.93756E+02 -6.33367E-01  .      .      .      .   ******     .      .      .      .
  5     1.93753E+02 -6.31432E-01  .      .      .      .   ******     .      .      .      .
  6     1.93759E+02 -6.34722E-01  .      .      .      .   ******     .      .      .      .
  7     1.93759E+02 -6.34451E-01  .      .      .      .   ******     .      .      .      .
  8     1.93759E+02 -6.34873E-01  .      .      .      .   ******     .      .      .      .
  9     1.93759E+02 -6.34839E-01  .      .      .      .   ******     .      .      .      .
                                 .........................................................
                             |      |      |      |      |      |      |      |      |
                        -5.0000E+00                        0.0000E+00                        5.0000E+00

                                        ******************************************
                                        *** TEST FREQ #  8 vs. ANAL FREQ #  8 ***
                                        ***    % Diff Between Anal & Test     ***
                                        ***   (Test Freq =  2.00154E+02 Hz)   ***
                                        ******************************************
                        -1.0000E+01                        0.0000E+00                        1.0000E+01
                             |      |      |      |      |      |      |      |      |
CYCLE#   ANAL FREQ    PCT DIFF   .........................................................
 ---    2.13381E+02 -6.60842E+00  .      .  ***************************    .      .      .      .
  1     2.02209E+02 -1.02692E+00  .      .      .      .     *****  .      .      .      .
  2     2.04341E+02 -2.09168E+00  .      .      .      . *********  .      .      .      .
  3     2.04226E+02 -2.03449E+00  .      .      .      . *********  .      .      .      .
  4     2.04263E+02 -2.05274E+00  .      .      .      . *********  .      .      .      .
  5     2.04249E+02 -2.04575E+00  .      .      .      . *********  .      .      .      .
  6     2.04253E+02 -2.04774E+00  .      .      .      . *********  .      .      .      .
  7     2.04251E+02 -2.04684E+00  .      .      .      . *********  .      .      .      .
  8     2.04251E+02 -2.04709E+00  .      .      .      . *********  .      .      .      .
  9     2.04251E+02 -2.04697E+00  .      .      .      . *********  .      .      .      .
                                 .........................................................
                             |      |      |      |      |      |      |      |      |
                        -1.0000E+01                        0.0000E+00                        1.0000E+01
```

```
                                       ******************************************
                                       *** TEST FREQ #  9 vs. ANAL FREQ #  9 ***
                                       ***     % Diff Between Anal & Test     ***
                                       ***    (Test Freq =  2.00195E+02 Hz)   ***
                                       ******************************************
                         -1.0000E+01                   0.0000E+00                    1.0000E+01
                              |         |         |         |         |         |         |         |         |
CYCLE#    ANAL FREQ    PCT DIFF   .................................................................................
 ---     2.13732E+02  -6.76166E+00  .         .  *****************************         .         .         .         .
  1      2.02515E+02  -1.15880E+00  .         .         .         .    ******         .         .         .         .
  2      2.04644E+02  -2.22255E+00  .         .         .         .**********         .         .         .         .
  3      2.04527E+02  -2.16397E+00  .         .         .         .**********         .         .         .         .
  4      2.04563E+02  -2.18195E+00  .         .         .         .**********         .         .         .         .
  5      2.04549E+02  -2.17476E+00  .         .         .         .**********         .         .         .         .
  6      2.04553E+02  -2.17672E+00  .         .         .         .**********         .         .         .         .
  7      2.04551E+02  -2.17578E+00  .         .         .         .**********         .         .         .         .
  8      2.04551E+02  -2.17603E+00  .         .         .         .**********         .         .         .         .
  9      2.04551E+02  -2.17591E+00  .         .         .         .**********         .         .         .         .
                                  .................................................................................
                              |         |         |         |         |         |         |         |         |
                         -1.0000E+01                   0.0000E+00                    1.0000E+01
```

```
                              ++++++++++++++++++++++++++++++++++++++++++
                              +++ TEST VECT #  1 vs. ANAL VECT #  2 +++
                              +++     % Diff Between Anal & Test     +++
                              ++++++++++++++++++++++++++++++++++++++++++
                    |AVG % Difference|                      MAX % Difference
               0.0                          5.00000E+01|0.0                        5.00000E+01
               |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) ......................................................................... CYCLE#  MAX DIFF(%)
 ---    2.95723E+00 |**      .         .         .         |*****    .         .         .         |  ---    6.71461E+00
  1     5.58395E+00 |****    .         .         .         |*************      .         .         |   1     1.63496E+01
  2     5.39692E+00 |****    .         .         .         |*************      .         .         |   2     1.60422E+01
  3     5.28971E+00 |****    .         .         .         |*************      .         .         |   3     1.57986E+01
  4     5.30367E+00 |****    .         .         .         |*************      .         .         |   4     1.58310E+01
  5     5.29739E+00 |****    .         .         .         |*************      .         .         |   5     1.58158E+01
  6     5.29946E+00 |****    .         .         .         |*************      .         .         |   6     1.58206E+01
  7     5.29868E+00 |****    .         .         .         |*************      .         .         |   7     1.58187E+01
  8     5.29895E+00 |****    .         .         .         |*************      .         .         |   8     1.58193E+01
  9     5.29885E+00 |****    .         .         .         |*************      .         .         |   9     1.58190E+01
               .........................................................................
               |         |         |         |         |         |         |         |         |
               0.0                          5.00000E+01|0.0                        5.00000E+01

                              ++++++++++++++++++++++++++++++++++++++++++
                              +++ TEST VECT #  2 vs. ANAL VECT #  1 +++
                              +++     % Diff Between Anal & Test     +++
                              ++++++++++++++++++++++++++++++++++++++++++
                    |AVG % Difference|                      MAX % Difference
               0.0                          5.00000E+01|0.0                        5.00000E+01
               |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) ......................................................................... CYCLE#  MAX DIFF(%)
 ---    9.30762E+00 |*******  .         .         .        |**************     .         .         |  ---    1.80649E+01
  1     2.99075E+00 |**      .         .         .         |*****    .         .         .         |   1     5.88311E+00
  2     3.17085E+00 |***     .         .         .         |*****    .         .         .         |   2     6.17783E+00
  3     3.27315E+00 |***     .         .         .         |*****    .         .         .         |   3     6.41093E+00
  4     3.25985E+00 |***     .         .         .         |*****    .         .         .         |   4     6.37996E+00
  5     3.26583E+00 |***     .         .         .         |*****    .         .         .         |   5     6.39446E+00
  6     3.26385E+00 |***     .         .         .         |*****    .         .         .         |   6     6.38994E+00
  7     3.26460E+00 |***     .         .         .         |*****    .         .         .         |   7     6.39176E+00
  8     3.26434E+00 |***     .         .         .         |*****    .         .         .         |   8     6.39116E+00
  9     3.26444E+00 |***     .         .         .         |*****    .         .         .         |   9     6.39140E+00
               .........................................................................
               |         |         |         |         |         |         |         |         |
               0.0                          5.00000E+01|0.0                        5.00000E+01
```

```
                         +++++++++++++++++++++++++++++++++++++++++
                         +++ TEST VECT #  4 vs. ANAL VECT #  4 +++
                         +++    % Diff Between Anal & Test     +++
                         +++++++++++++++++++++++++++++++++++++++++
             |AVG % Difference|                          MAX % Difference
          0.0                          5.00000E+01|0.0                         5.00000E+01
          |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) ................................................................................ CYCLE#  MAX DIFF(%)
 ---    9.67540E+00 |******** .         .         .         |****************** .         .         |  ---   2.22096E+01
  1     1.10195E+01 |*********.         .         .         |****************   .         .         |   1    1.94391E+01
  2     1.00397E+01 |******** .         .         .         |**************     .         .         |   2    1.76035E+01
  3     1.02358E+01 |******** .         .         .         |**************     .         .         |   3    1.76959E+01
  4     1.01689E+01 |******** .         .         .         |**************     .         .         |   4    1.75880E+01
  5     1.02012E+01 |******** .         .         .         |**************     .         .         |   5    1.76111E+01
  6     1.01931E+01 |******** .         .         .         |**************     .         .         |   6    1.75989E+01
  7     1.01974E+01 |******** .         .         .         |**************     .         .         |   7    1.76019E+01
  8     1.01963E+01 |******** .         .         .         |**************     .         .         |   8    1.76003E+01
  9     1.01969E+01 |******** .         .         .         |**************     .         .         |   9    1.76007E+01

                    ................................................................................
                    |         |         |         |         |         |         |         |         |
                    0.0                          5.00000E+01|0.0                         5.00000E+01


                         +++++++++++++++++++++++++++++++++++++++++
                         +++ TEST VECT #  5 vs. ANAL VECT #  5 +++
                         +++    % Diff Between Anal & Test     +++
                         +++++++++++++++++++++++++++++++++++++++++
             |AVG % Difference|                          MAX % Difference
          0.0                          5.00000E+01|0.0                         5.00000E+01
          |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) ................................................................................ CYCLE#  MAX DIFF(%)
 ---    1.60770E+01 |*************      .         .         |**********************       .         |  ---   2.78187E+01
  1     9.75636E+00 |******** .         .         .         |**************     .         .         |   1    1.77146E+01
  2     1.02716E+01 |******** .         .         .         |****************   .         .         |   2    2.00771E+01
  3     1.00322E+01 |******** .         .         .         |****************   .         .         |   3    1.95319E+01
  4     1.01225E+01 |******** .         .         .         |****************   .         .         |   4    1.97115E+01
  5     1.00827E+01 |******** .         .         .         |****************   .         .         |   5    1.96227E+01
  6     1.00934E+01 |******** .         .         .         |****************   .         .         |   6    1.96444E+01
  7     1.00882E+01 |******** .         .         .         |****************   .         .         |   7    1.96327E+01
  8     1.00895E+01 |******** .         .         .         |****************   .         .         |   8    1.96355E+01
  9     1.00888E+01 |******** .         .         .         |****************   .         .         |   9    1.96340E+01

                    ................................................................................
                    |         |         |         |         |         |         |         |         |
                    0.0                          5.00000E+01|0.0                         5.00000E+01
```

```
                    +++++++++++++++++++++++++++++++++++++++++
                    +++ TEST VECT #  8 vs. ANAL VECT #  8 +++
                    +++    % Diff Between Anal & Test     +++
                    +++++++++++++++++++++++++++++++++++++++++
                           |AVG % Difference|                          MAX % Difference
                    0.0                          1.00000E+02|0.0                          1.00000E+02
                    |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) .................................................................................  CYCLE#  MAX DIFF(%)
 ---    3.62200E+01 |**************     .         .         |*******************************        |   ---    7.71070E+01
   1    3.06611E+01 |************       .         .         |*****************************.         |    1     7.29101E+01
   2    3.06129E+01 |************       .         .         |*****************************.         |    2     7.25378E+01
   3    3.03963E+01 |************       .         .         |*****************************.         |    3     7.18303E+01
   4    3.03632E+01 |************       .         .         |*****************************.         |    4     7.17324E+01
   5    3.03321E+01 |************       .         .         |*****************************.         |    5     7.16385E+01
   6    3.03275E+01 |************       .         .         |*****************************.         |    6     7.16247E+01
   7    3.03233E+01 |************       .         .         |*****************************.         |    7     7.16123E+01
   8    3.03227E+01 |************       .         .         |*****************************.         |    8     7.16105E+01
   9    3.03221E+01 |************       .         .         |*****************************.         |    9     7.16088E+01

                    .................................................................................
                    |         |         |         |         |         |         |         |         |
                    0.0                          1.00000E+02|0.0                          1.00000E+02


                    +++++++++++++++++++++++++++++++++++++++++
                    +++ TEST VECT #  9 vs. ANAL VECT #  9 +++
                    +++    % Diff Between Anal & Test     +++
                    +++++++++++++++++++++++++++++++++++++++++
                           |AVG % Difference|                          MAX % Difference
                    0.0                          5.00000E+01|0.0                          5.00000E+01
                    |         |         |         |         |         |         |         |         |
CYCLE#  AVG DIFF(%) .................................................................................  CYCLE#  MAX DIFF(%)
 ---    1.77106E+01 |**************     .         .         |*******************.         .         |   ---    2.34204E+01
   1    1.16377E+01 |*********.         .         .         |****************** .         .         |    1     2.28733E+01
   2    1.14773E+01 |*********.         .         .         |****************** .         .         |    2     2.26017E+01
   3    1.11969E+01 |*********.         .         .         |****************** .         .         |    3     2.24731E+01
   4    1.11808E+01 |*********.         .         .         |****************** .         .         |    4     2.25057E+01
   5    1.11415E+01 |*********.         .         .         |****************** .         .         |    5     2.24894E+01
   6    1.11394E+01 |*********.         .         .         |****************** .         .         |    6     2.24943E+01
   7    1.11342E+01 |*********.         .         .         |****************** .         .         |    7     2.24922E+01
   8    1.11339E+01 |*********.         .         .         |****************** .         .         |    8     2.24928E+01
   9    1.11332E+01 |*********.         .         .         |****************** .         .         |    9     2.24926E+01

                    .................................................................................
                    |         |         |         |         |         |         |         |         |
                    0.0                          5.00000E+01|0.0                          5.00000E+01
```

```
                                                                                           ******************************
                                                                                           ***  OBJECTIVE FUNCTION  ***
                                                                                           ***     MINIMIZATION     ***
                                                                                           ***   (PERCENT CHANGE)   ***
                                                                                           ******************************

                               0.0000E+00                              5.0000E+01                              1.0000E+02
                                   |         |         |         |         |         |         |         |         |
CYCLE#    OBJ FUNCT    PCT CHANGE  .................................................................................
  ---    1.63263E+02  ------ -     *********************************************************************************
  1      8.90488E+01  5.45430E+01  *********************************************     .         .         .         .
  2      8.54555E+01  5.23421E+01  *******************************************       .         .         .         .
  3      8.53686E+01  5.22889E+01  *******************************************       .         .         .         .
  4      8.53584E+01  5.22826E+01  *******************************************       .         .         .         .
  5      8.53570E+01  5.22818E+01  *******************************************       .         .         .         .
  6      8.53569E+01  5.22817E+01  *******************************************       .         .         .         .
  7      8.53568E+01  5.22817E+01  *******************************************       .         .         .         .
  8      8.53568E+01  5.22817E+01  *******************************************       .         .         .         .
  9      8.53568E+01  5.22817E+01  *******************************************       .         .         .         .

                                   .................................................................................
                                   |         |         |         |         |         |         |         |         |
                               0.0000E+00                              5.0000E+01                              1.0000E+02
```

****
** REVISED PARAMETER INFORMATION **
****

*** TEN BAY TRUSS ***

PARAMETER NAME	ORIG EST	REV EST	ORIG STD DEV	REV STD DEV
BAY 1&2 DIAG STIFF	1.00000D+00	1.11385D+00	2.00000D-01	1.94691D-01
BAY 1&2 NON-DIAG STF	1.00000D+00	9.12968D-01	2.00000D-01	1.81126D-01
BAY 3&4 DIAG STIFF	1.00000D+00	1.09334D+00	2.00000D-01	1.71692D-01
BAY 3&4 NON-DIAG STF	1.00000D+00	1.16886D+00	2.00000D-01	1.12349D-01
BAY 5&6 DIAG STIFF	1.00000D+00	1.11412D+00	2.00000D-01	1.71305D-01
BAY 5&6 NON-DIAG STF	1.00000D+00	1.02933D+00	2.00000D-01	1.26110D-01
BAY 7&8 DIAG STIFF	1.00000D+00	1.26928D+00	2.00000D-01	1.72925D-01
BAY 7&8 NON-DIAG STF	1.00000D+00	5.75098D-01	2.00000D-01	1.05353D-01
BAY 9&10 DIAG STIFF	1.00000D+00	5.00591D-01	2.00000D-01	6.31724D-02
BAY 9&10 NON-DIAG SF	1.00000D+00	1.22932D+00	2.00000D-01	4.98045D-02
BAY 1&2 X-ROT INERT	0.00000D+00	-2.45721D-02	1.40000D-02	1.17279D-02
BAY 3&4 X-ROT INERT	0.00000D+00	-2.50467D-02	1.40000D-02	1.25643D-02
BAY 5&6 X-ROT INERT	0.00000D+00	-1.83685D-02	1.40000D-02	1.32502D-02
BAY 7&8 X-ROT INERT	0.00000D+00	-6.21965D-03	1.40000D-02	1.27058D-02
BAY 9&10 X-ROT INERT	0.00000D+00	4.46180D-05	1.40000D-02	1.34704D-02

****
*** PARAMETER CORRELATION SUMMARY ***
*** (CORRELATION THRESHOLD = 0.90) **
****

COMPONENT / PARAMETER	CORRELATED COMPONENT	CORRELATED PARAMETERS & (CORRELATION COEFFICIENT)

***** PARAMETERS ARE ALL UNCORRELATED *****
***** W.R.T. CORRELATION THRESHOLD *****

```
*****************************************************
** STATISTICAL SIGNIFICANCE OF PARAMETER ESTIMATES **
*****************************************************


                 *** TEN BAY TRUSS        ***

  *PARAMETER*       -4===================-2==================0===================+2==================+4
BAY 1&2 DIAG STIFF   |                          X------------------0-------------------X             |
BAY 1&2 NON-DIAG STF |                 X-----------------0-----------------X                         |
BAY 3&4 DIAG STIFF   |                           X----------------0-----------------X                |
BAY 3&4 NON-DIAG STF |                                    X----------0----------X                    |
BAY 5&6 DIAG STIFF   |                            X----------------0-----------------X               |
BAY 5&6 NON-DIAG STF |                           X------------0------------X                         |
BAY 7&8 DIAG STIFF   |                                   X----------------0-----------------X        |
BAY 7&8 NON-DIAG STF |       X----------0----------X                                                 |
BAY 9&10 DIAG STIFF  |        X-----0-----X                                                          |
BAY 9&10 NON-DIAG SF |                                             X----0----X                       |
BAY 1&2 X-ROT INERT  |    X----------------0----------------X                                        |
BAY 3&4 X-ROT INERT  |   X-----------------0-----------------X                                       |
BAY 5&6 X-ROT INERT  |       X------------------0------------------X                                 |
BAY 7&8 X-ROT INERT  |                 X-----------------0-----------------X                         |
BAY 9&10 X-ROT INERT |                    X------------------0------------------X                    |
                    -4===================-2==================0===================+2==================+4
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
                                             *** BAY 1&2 DIAG STIFF    ***
                                          (% CHANGE FROM ORIG PARAMETER VALUE)
                       -5.0000E+01                            0.0000E+00                             5.0000E+01
                           I         I         I         I         I         I         I         I         I
CYCLE#    PARM VALUE    PCT CHANGE .................................................................................
 ---      1.00000E+00    ------    .         .         .         .         *         .         .         .         .
  1       1.14962E+00  1.49616E+01 .         .         .         .         *************       .         .         .
  2       1.11710E+00  1.17103E+01 .         .         .         .         **********.         .         .         .
  3       1.11503E+00  1.15034E+01 .         .         .         .         **********.         .         .         .
  4       1.11451E+00  1.14512E+01 .         .         .         .         **********.         .         .         .
  5       1.11402E+00  1.14024E+01 .         .         .         .         **********.         .         .         .
  6       1.11394E+00  1.13939E+01 .         .         .         .         **********.         .         .         .
  7       1.11388E+00  1.13875E+01 .         .         .         .         **********.         .         .         .
  8       1.11386E+00  1.13863E+01 .         .         .         .         **********.         .         .         .
  9       1.11385E+00  1.13855E+01 .         .         .         .         **********.         .         .         .
                                   .................................................................................
                                   I         I         I         I         I         I         I         I         I
                       -5.0000E+01                            0.0000E+00                             5.0000E+01

                                             *** BAY 1&2 NON-DIAG STF ***
                                          (% CHANGE FROM ORIG PARAMETER VALUE)
                       -1.0000E+01                            0.0000E+00                             1.0000E+01
                           I         I         I         I         I         I         I         I         I
CYCLE#    PARM VALUE    PCT CHANGE .................................................................................
 ---      1.00000E+00    ------    .         .         .         .         *         .         .         .         .
  1       1.07218E+00  7.21755E+00 .         .         .         .         ******************************.         .
  2       9.53659E-01 -4.63411E+00 .         .         .*******************         .         .         .         .
  3       9.29262E-01 -7.07382E+00 .         . *****************************         .         .         .         .
  4       9.17894E-01 -8.21056E+00 .     *********************************         .         .         .         .
  5       9.15039E-01 -8.49609E+00 .    **********************************         .         .         .         .
  6       9.13587E-01 -8.64130E+00 .   ***********************************         .         .         .         .
  7       9.13209E-01 -8.67906E+00 .   ***********************************         .         .         .         .
  8       9.13018E-01 -8.69821E+00 .   ***********************************         .         .         .         .
  9       9.12968E-01 -8.70325E+00 .   ***********************************         .         .         .         .
                                   .................................................................................
                                   I         I         I         I         I         I         I         I         I
                       -1.0000E+01                            0.0000E+00                             1.0000E+01
```

```
                                                            *** BAY 3&4 DIAG STIFF    ***
                                                        (% CHANGE FROM ORIG PARAMETER VALUE)
                               -5.0000E+01                            0.0000E+00                              5.0000E+01
                                    |         |         |         |         |         |         |         |         |
CYCLE#  PARM VALUE    PCT CHANGE    .................................................................................
  ---   1.00000E+00   ------        .         .         .         .         *         .         .         .         .
   1    1.11856E+00   1.18562E+01   .         .         .         .         **********.         .         .         .
   2    1.10192E+00   1.01920E+01   .         .         .         .         ********* .         .         .         .
   3    1.09513E+00   9.51326E+00   .         .         .         .         ********* .         .         .         .
   4    1.09424E+00   9.42429E+00   .         .         .         .         ********* .         .         .         .
   5    1.09355E+00   9.35459E+00   .         .         .         .         ********  .         .         .         .
   6    1.09345E+00   9.34494E+00   .         .         .         .         ********  .         .         .         .
   7    1.09336E+00   9.33597E+00   .         .         .         .         ********  .         .         .         .
   8    1.09335E+00   9.33468E+00   .         .         .         .         ********  .         .         .         .
   9    1.09334E+00   9.33350E+00   .         .         .         .         ********  .         .         .         .

                                    .................................................................................
                                    |         |         |         |         |         |         |         |         |
                               -5.0000E+01                            0.0000E+00                              5.0000E+01
```

```
                                                            *** BAY 3&4 NON-DIAG STF ***
                                                        (% CHANGE FROM ORIG PARAMETER VALUE)
                               -5.0000E+01                            0.0000E+00                              5.0000E+01
                                    |         |         |         |         |         |         |         |         |
CYCLE#  PARM VALUE    PCT CHANGE    .................................................................................
  ---   1.00000E+00   ------        .         .         .         .         *         .         .         .         .
   1    1.06497E+00   6.49687E+00   .         .         .         .         ******    .         .         .         .
   2    1.15691E+00   1.56912E+01   .         .         .         .         **************      .         .         .
   3    1.16272E+00   1.62725E+01   .         .         .         .         **************      .         .         .
   4    1.16717E+00   1.67174E+01   .         .         .         .         **************      .         .         .
   5    1.16811E+00   1.68108E+01   .         .         .         .         **************      .         .         .
   6    1.16864E+00   1.68642E+01   .         .         .         .         **************      .         .         .
   7    1.16877E+00   1.68770E+01   .         .         .         .         ***************     .         .         .
   8    1.16884E+00   1.68840E+01   .         .         .         .         ***************     .         .         .
   9    1.16886E+00   1.68857E+01   .         .         .         .         ***************     .         .         .

                                    .................................................................................
                                    |         |         |         |         |         |         |         |         |
                               -5.0000E+01                            0.0000E+00                              5.0000E+01
```

```
                                                  *** BAY 5&6 DIAG STIFF    ***
                                             (% CHANGE FROM ORIG PARAMETER VALUE)
                         -5.0000E+01                      0.0000E+00                        5.0000E+01
                              |        |        |        |        |        |        |        |        |
CYCLE#   PARM VALUE   PCT CHANGE  .........................................................................
 ---     1.00000E+00   ------     .        .        .        .    *   .        .        .        .
  1      1.09028E+00  9.02804E+00 .        .        .        .    ********.    .        .        .
  2      1.08616E+00  8.61563E+00 .        .        .        .    ********.    .        .        .
  3      1.10784E+00  1.07836E+01 .        .        .        .    **********.  .        .        .
  4      1.11056E+00  1.10562E+01 .        .        .        .    **********.  .        .        .
  5      1.11325E+00  1.13252E+01 .        .        .        .    **********.  .        .        .
  6      1.11367E+00  1.13666E+01 .        .        .        .    **********.  .        .        .
  7      1.11401E+00  1.14014E+01 .        .        .        .    **********.  .        .        .
  8      1.11407E+00  1.14071E+01 .        .        .        .    **********.  .        .        .
  9      1.11412E+00  1.14117E+01 .        .        .        .    **********.  .        .        .
                                  .........................................................................
                              |        |        |        |        |        |        |        |        |
                         -5.0000E+01                      0.0000E+00                        5.0000E+01
```

```
                                                  *** BAY 5&6 NON-DIAG STF ***
                                             (% CHANGE FROM ORIG PARAMETER VALUE)
                         -5.0000E+00                      0.0000E+00                        5.0000E+00
                              |        |        |        |        |        |        |        |        |
CYCLE#   PARM VALUE   PCT CHANGE  .........................................................................
 ---     1.00000E+00   ------     .        .        .        .    *        .        .        .        .
  1      1.01390E+00  1.39000E+00 .        .        .        .    ************      .        .        .
  2      1.02875E+00  2.87464E+00 .        .        .        .    *************************    .        .
  3      1.03149E+00  3.14904E+00 .        .        .        .    ***************************  .        .
  4      1.02907E+00  2.90678E+00 .        .        .        .    *************************    .        .
  5      1.02962E+00  2.96202E+00 .        .        .        .    **************************   .        .
  6      1.02929E+00  2.92922E+00 .        .        .        .    *************************    .        .
  7      1.02936E+00  2.93645E+00 .        .        .        .    *************************    .        .
  8      1.02932E+00  2.93217E+00 .        .        .        .    *************************    .        .
  9      1.02933E+00  2.93310E+00 .        .        .        .    *************************    .        .
                                  .........................................................................
                              |        |        |        |        |        |        |        |        |
                         -5.0000E+00                      0.0000E+00                        5.0000E+00
```

```
                                               *** BAY 7&8 DIAG STIFF   ***
                                          (% CHANGE FROM ORIG PARAMETER VALUE)
                               -5.0000E+01                             0.0000E+00                              5.0000E+01
                                  |         |         |         |         |         |         |         |         |
CYCLE#   PARM VALUE    PCT CHANGE .................................................................................
  ---    1.00000E+00   ------     .         .         .         .         *         .         .         .         .
   1     1.36485E+00  3.64851E+01 .         .         .         .         ******************************.         .
   2     1.25352E+00  2.53518E+01 .         .         .         .         *********************         .         .
   3     1.27949E+00  2.79492E+01 .         .         .         .         ***********************       .         .
   4     1.26725E+00  2.67246E+01 .         .         .         .         **********************        .         .
   5     1.27059E+00  2.70593E+01 .         .         .         .         ***********************       .         .
   6     1.26900E+00  2.69001E+01 .         .         .         .         ***********************       .         .
   7     1.26943E+00  2.69434E+01 .         .         .         .         ***********************       .         .
   8     1.26923E+00  2.69227E+01 .         .         .         .         ***********************       .         .
   9     1.26928E+00  2.69283E+01 .         .         .         .         ***********************       .         .

                                  .................................................................................
                                  |         |         |         |         |         |         |         |         |
                               -5.0000E+01                             0.0000E+00                              5.0000E+01
```

```
                                               *** BAY 7&8 NON-DIAG STF ***
                                          (% CHANGE FROM ORIG PARAMETER VALUE)
                               -5.0000E+01                             0.0000E+00                              5.0000E+01
                                  |         |         |         |         |         |         |         |         |
CYCLE#   PARM VALUE    PCT CHANGE .................................................................................
  ---    1.00000E+00   ------     .         .         .         .         *         .         .         .         .
   1     5.30287E-01 -4.69713E+01 . ***************************************         .         .         .         .
   2     5.81927E-01 -4.18073E+01 .      **********************************         .         .         .         .
   3     5.73398E-01 -4.26602E+01 .     ***********************************         .         .         .         .
   4     5.76132E-01 -4.23868E+01 .     ***********************************         .         .         .         .
   5     5.74868E-01 -4.25132E+01 .     ***********************************         .         .         .         .
   6     5.75238E-01 -4.24762E+01 .     ***********************************         .         .         .         .
   7     5.75072E-01 -4.24928E+01 .     ***********************************         .         .         .         .
   8     5.75120E-01 -4.24880E+01 .     ***********************************         .         .         .         .
   9     5.75098E-01 -4.24902E+01 .     ***********************************         .         .         .         .

                                  .................................................................................
                                  |         |         |         |         |         |         |         |         |
                               -5.0000E+01                             0.0000E+00                              5.0000E+01
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                                                  *** BAY 9&10 DIAG STIFF  ***
                                              (% CHANGE FROM ORIG PARAMETER VALUE)
                         -1.0000E+02                        0.0000E+00                          1.0000E+02
                             |      |      |      |      |      |      |      |      |
CYCLE#   PARM VALUE   PCT CHANGE .........................................................
 ----    1.00000E+00   ------    .      .      .      .      *      .      .      .      .
  1      4.94532E-01 -5.05468E+01 .     .      *********************      .      .      .      .
  2      5.15625E-01 -4.84375E+01 .     .      .********************      .      .      .      .
  3      5.01718E-01 -4.98282E+01 .     .      *********************      .      .      .      .
  4      5.02588E-01 -4.97412E+01 .     .      *********************      .      .      .      .
  5      5.00752E-01 -4.99248E+01 .     .      *********************      .      .      .      .
  6      5.00851E-01 -4.99149E+01 .     .      *********************      .      .      .      .
  7      5.00610E-01 -4.99390E+01 .     .      *********************      .      .      .      .
  8      5.00622E-01 -4.99378E+01 .     .      *********************      .      .      .      .
  9      5.00591E-01 -4.99409E+01 .     .      *********************      .      .      .      .
                                 .........................................................
                             |      |      |      |      |      |      |      |      |
                         -1.0000E+02                        0.0000E+00                          1.0000E+02

                                                  *** BAY 9&10 NON-DIAG SF ***
                                              (% CHANGE FROM ORIG PARAMETER VALUE)
                         -5.0000E+01                        0.0000E+00                          5.0000E+01
                             |      |      |      |      |      |      |      |      |
CYCLE#   PARM VALUE   PCT CHANGE .........................................................
 ----    1.00000E+00   ------    .      .      .      .      *      .      .      .      .
  1      1.23404E+00  2.34041E+01 .     .      .      .      ********************.      .      .
  2      1.22177E+00  2.21773E+01 .     .      .      .      ******************* .      .      .
  3      1.22978E+00  2.29776E+01 .     .      .      .      ******************* .      .      .
  4      1.22844E+00  2.28435E+01 .     .      .      .      ******************* .      .      .
  5      1.22938E+00  2.29378E+01 .     .      .      .      ******************* .      .      .
  6      1.22920E+00  2.29204E+01 .     .      .      .      ******************* .      .      .
  7      1.22933E+00  2.29327E+01 .     .      .      .      ******************* .      .      .
  8      1.22930E+00  2.29305E+01 .     .      .      .      ******************* .      .      .
  9      1.22932E+00  2.29321E+01 .     .      .      .      ******************* .      .      .
                                 .........................................................
                             |      |      |      |      |      |      |      |      |
                         -5.0000E+01                        0.0000E+00                          5.0000E+01
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                                                  *** BAY 1&2 X-ROT INERT  ***
                                                ( CHANGE FROM ORIG PARAMETER VALUE )
                              -5.0000E-02                             0.0000E+00                              5.0000E-02
                                    |         |         |         |         |         |         |         |         |
CYCLE#   PARM VALUE    PARM CHANGE  .................................................................................
 ---     0.00000E+00    ------      .         .         .         .         *         .         .         .         .
  1      -2.16034E-02  -2.16034E-02 .         .         .  ******************         .         .         .         .
  2      -2.43801E-02  -2.43801E-02 .         .         *********************         .         .         .         .
  3      -2.45050E-02  -2.45050E-02 .         .         *********************         .         .         .         .
  4      -2.45753E-02  -2.45753E-02 .         .         *********************         .         .         .         .
  5      -2.45667E-02  -2.45667E-02 .         .         *********************         .         .         .         .
  6      -2.45729E-02  -2.45729E-02 .         .         *********************         .         .         .         .
  7      -2.45715E-02  -2.45715E-02 .         .         *********************         .         .         .         .
  8      -2.45723E-02  -2.45723E-02 .         .         *********************         .         .         .         .
  9      -2.45721E-02  -2.45721E-02 .         .         *********************         .         .         .         .

                                    .................................................................................
                                    |         |         |         |         |         |         |         |         |
                              -5.0000E-02                             0.0000E+00                              5.0000E-02
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                                                  *** BAY 3&4 X-ROT INERT  ***
                                                ( CHANGE FROM ORIG PARAMETER VALUE )
                              -5.0000E-02                             0.0000E+00                              5.0000E-02
                                    |         |         |         |         |         |         |         |         |
CYCLE#   PARM VALUE    PARM CHANGE  .................................................................................
 ---     0.00000E+00    ------      .         .         .         .         *         .         .         .         .
  1      -1.96531E-02  -1.96531E-02 .         .         .   *****************         .         .         .         .
  2      -2.46468E-02  -2.46468E-02 .         .         *********************         .         .         .         .
  3      -2.48122E-02  -2.48122E-02 .         .         *********************         .         .         .         .
  4      -2.50375E-02  -2.50375E-02 .         .         *********************         .         .         .         .
  5      -2.50205E-02  -2.50205E-02 .         .         *********************         .         .         .         .
  6      -2.50462E-02  -2.50462E-02 .         .         *********************         .         .         .         .
  7      -2.50437E-02  -2.50437E-02 .         .         *********************         .         .         .         .
  8      -2.50471E-02  -2.50471E-02 .         .         *********************         .         .         .         .
  9      -2.50467E-02  -2.50467E-02 .         .         *********************         .         .         .         .

                                    .................................................................................
                                    |         |         |         |         |         |         |         |         |
                              -5.0000E-02                             0.0000E+00                              5.0000E-02
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                                                                  *** BAY 5&6 X-ROT INERT  ***
                                                              ( CHANGE FROM ORIG PARAMETER VALUE )
                               -5.0000E-02                              0.0000E+00                             5.0000E-02
                                     |         |         |         |         |         |         |         |         |
CYCLE#    PARM VALUE    PARM CHANGE  .................................................................................
 ---      0.00000E+00   ------       .         .         .         .         *         .         .         .         .
  1      -1.26571E-02  -1.26571E-02  .         .         .         ***********         .         .         .         .
  2      -1.78368E-02  -1.78368E-02  .         .         .   ***************         .         .         .         .
  3      -1.81693E-02  -1.81693E-02  .         .         .  ****************         .         .         .         .
  4      -1.83337E-02  -1.83337E-02  .         .         .  ****************         .         .         .         .
  5      -1.83466E-02  -1.83466E-02  .         .         .  ****************         .         .         .         .
  6      -1.83646E-02  -1.83646E-02  .         .         .  ****************         .         .         .         .
  7      -1.83660E-02  -1.83660E-02  .         .         .  ****************         .         .         .         .
  8      -1.83683E-02  -1.83683E-02  .         .         .  ****************         .         .         .         .
  9      -1.83685E-02  -1.83685E-02  .         .         .  ****************         .         .         .         .
                                     .................................................................................
                                     |         |         |         |         |         |         |         |         |
                               -5.0000E-02                              0.0000E+00                             5.0000E-02

                                                                  *** BAY 7&8 X-ROT INERT  ***
                                                              ( CHANGE FROM ORIG PARAMETER VALUE )
                               -1.0000E-02                              0.0000E+00                             1.0000E-02
                                     |         |         |         |         |         |         |         |         |
CYCLE#    PARM VALUE    PARM CHANGE  .................................................................................
 ---      0.00000E+00   ------       .         .         .         .         *         .         .         .         .
  1      -4.09526E-03  -4.09526E-03  .         .         . *****************         .         .         .         .
  2      -6.05460E-03  -6.05460E-03  .         .*************************         .         .         .         .
  3      -6.09498E-03  -6.09498E-03  .         .*************************         .         .         .         .
  4      -6.18347E-03  -6.18347E-03  .         **************************         .         .         .         .
  5      -6.20431E-03  -6.20431E-03  .         **************************         .         .         .         .
  6      -6.21493E-03  -6.21493E-03  .         **************************         .         .         .         .
  7      -6.21788E-03  -6.21788E-03  .         **************************         .         .         .         .
  8      -6.21925E-03  -6.21925E-03  .         **************************         .         .         .         .
  9      -6.21965E-03  -6.21965E-03  .         **************************         .         .         .         .
                                     .................................................................................
                                     |         |         |         |         |         |         |         |         |
                               -1.0000E-02                              0.0000E+00                             1.0000E-02
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                                                          *** BAY 9&10 X-ROT INERT ***
                                                       ( CHANGE FROM ORIG PARAMETER VALUE )
                                   -5.0000E-04                         0.0000E+00                          5.0000E-04
                                        |         |         |         |         |         |         |         |         |
CYCLE#     PARM VALUE    PARM CHANGE    .........................................................................
 ---       0.00000E+00     ------       .         .         .         .         *         .         .         .         .
  1       -7.48983E-05  -7.48983E-05    .         .         .         .   *******         .         .         .         .
  2       -1.47054E-04  -1.47054E-04    .         .         .     *************           .         .         .         .
  3        5.54830E-05   5.54830E-05    .         .         .         .         *****     .         .         .         .
  4        4.23249E-05   4.23249E-05    .         .         .         .         ****      .         .         .         .
  5        4.63812E-05   4.63812E-05    .         .         .         .         *****     .         .         .         .
  6        4.44822E-05   4.44822E-05    .         .         .         .         *****     .         .         .         .
  7        4.48205E-05   4.48205E-05    .         .         .         .         *****     .         .         .         .
  8        4.45782E-05   4.45782E-05    .         .         .         .         *****     .         .         .         .
  9        4.46180E-05   4.46180E-05    .         .         .         .         *****     .         .         .         .

                                        .........................................................................
                                        |         |         |         |         |         |         |         |         |
                                   -5.0000E-04                         0.0000E+00                          5.0000E-04
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